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(54) Apparatus for tape laying and manufacture of composite structures

(57) An apparatus for forming composite, fiber/resin components from fibrous, resin-impregnated tape comprises a gantry 11 for positioning a tape applicator head assembly 413 over a mold structure 412, which defines a mold surface of planar or contoured configuration. A control system is employed to control the movement of the tape head 413 over the mold surface 412 comprising a programmable means for controlling movement in the longitudinal X-axis, the transverse X-axis, gross movement in a vertical Z and a rotational R-axis parallel to the X-axis and passing under the head 413. Primary and initial movement is controlled in accordance with a sequence command program in cooperation with a resident program in a digital computer. A second, adaptive control system is employed for enabling the tape dispensing head to follow vertical contours of the mold surface during X—Y movement across the surface, and provides a control means for fine adjustment of the tape head through the Z and R-axis such that the tape head is oriented substantially normal to the mold surface.

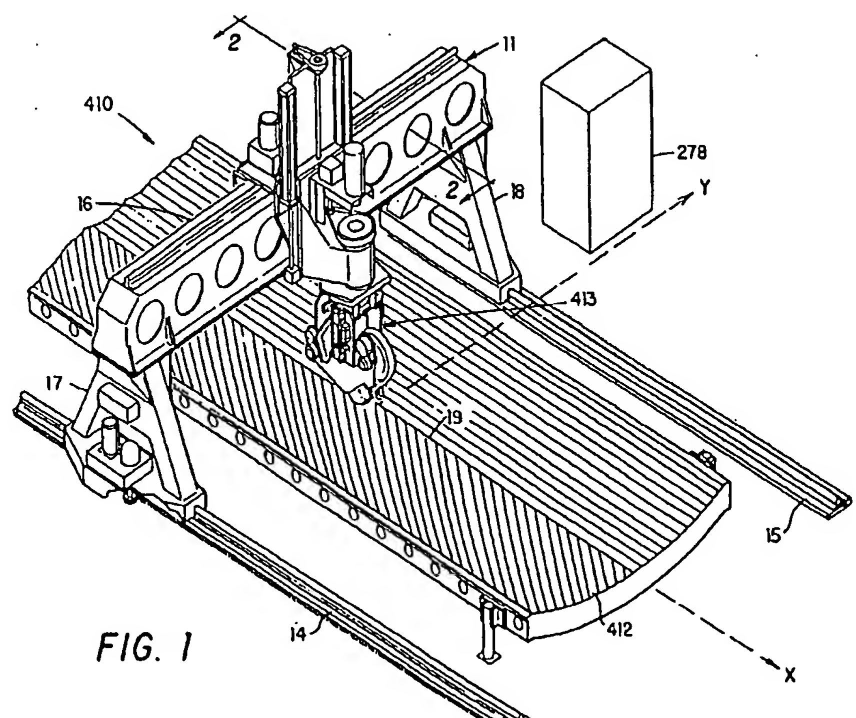

FIG. 1

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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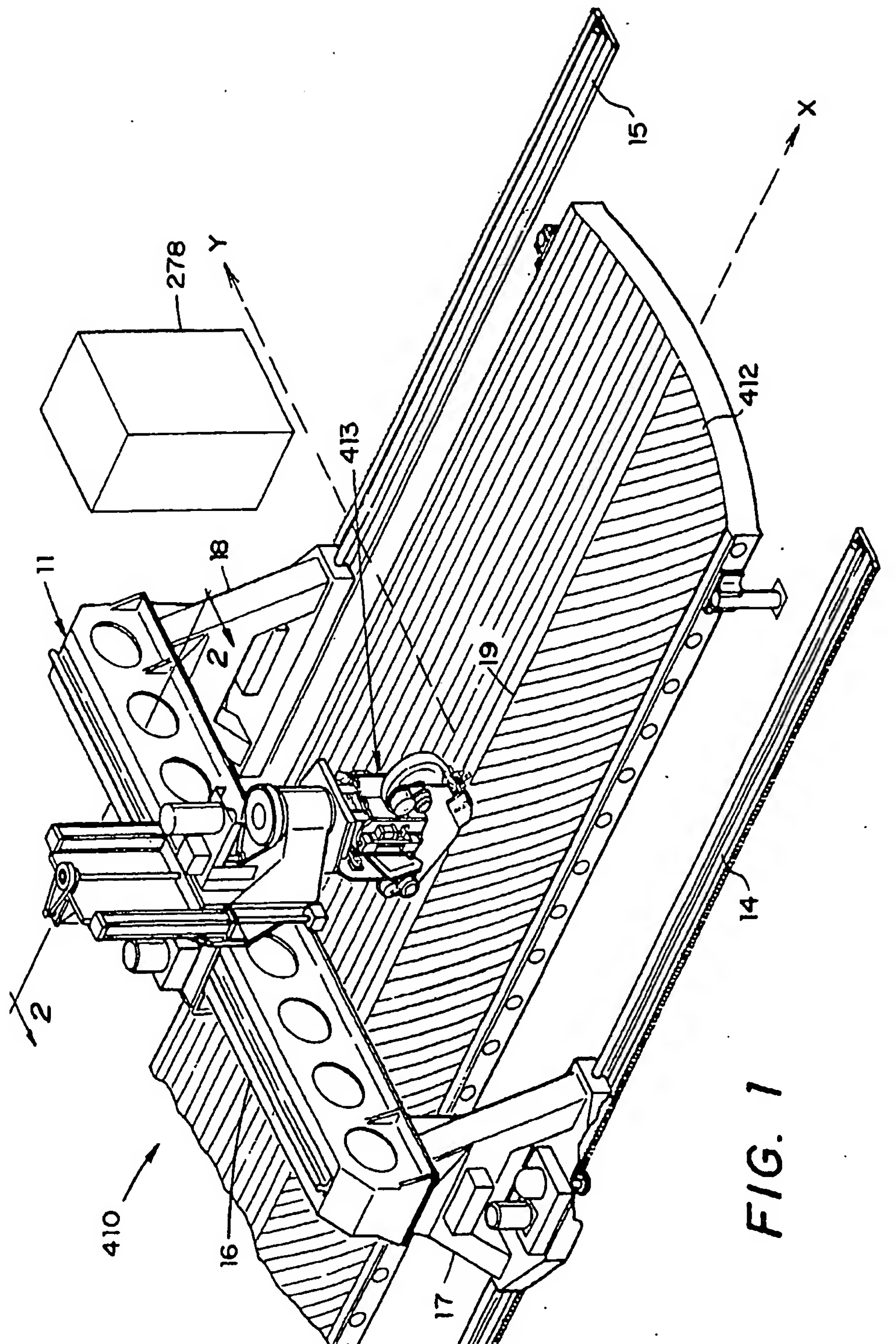
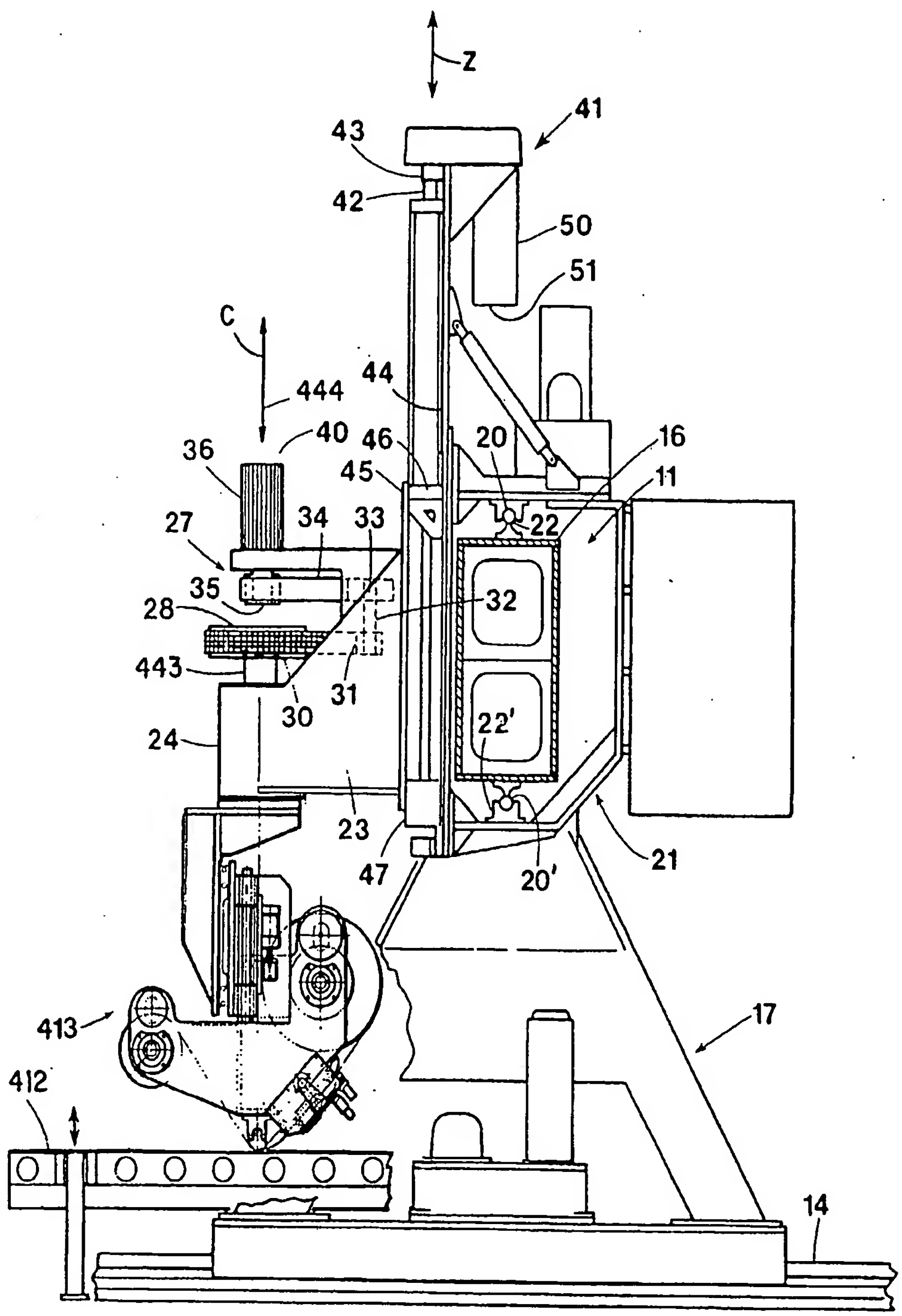


FIG. 1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413
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412
14

FIG. 2

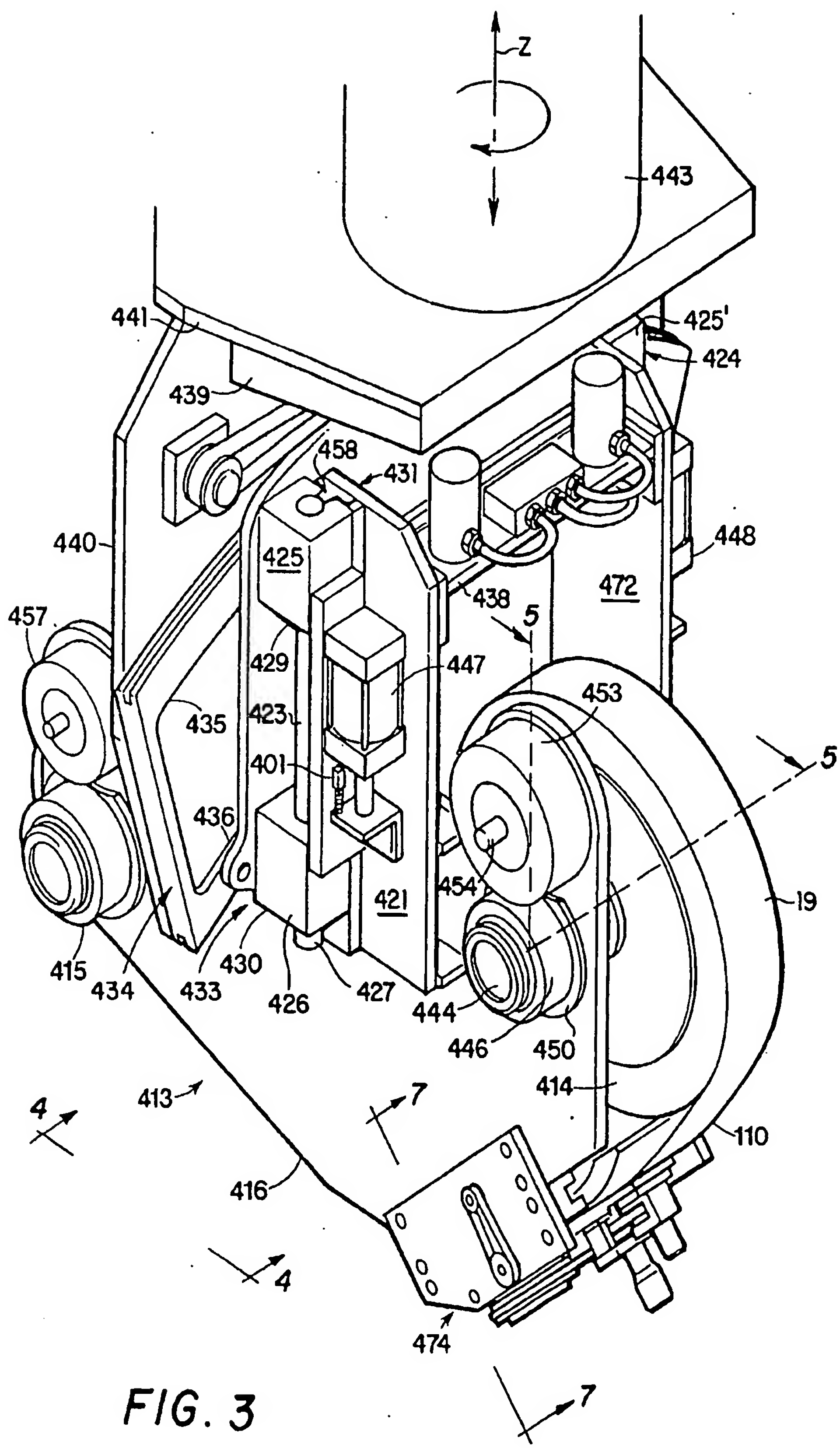
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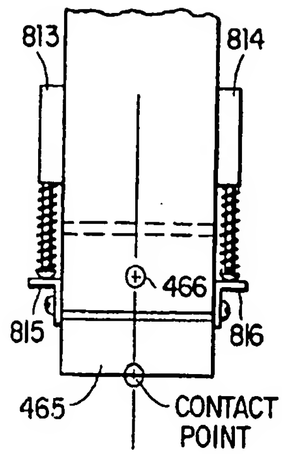
FIG. 3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816
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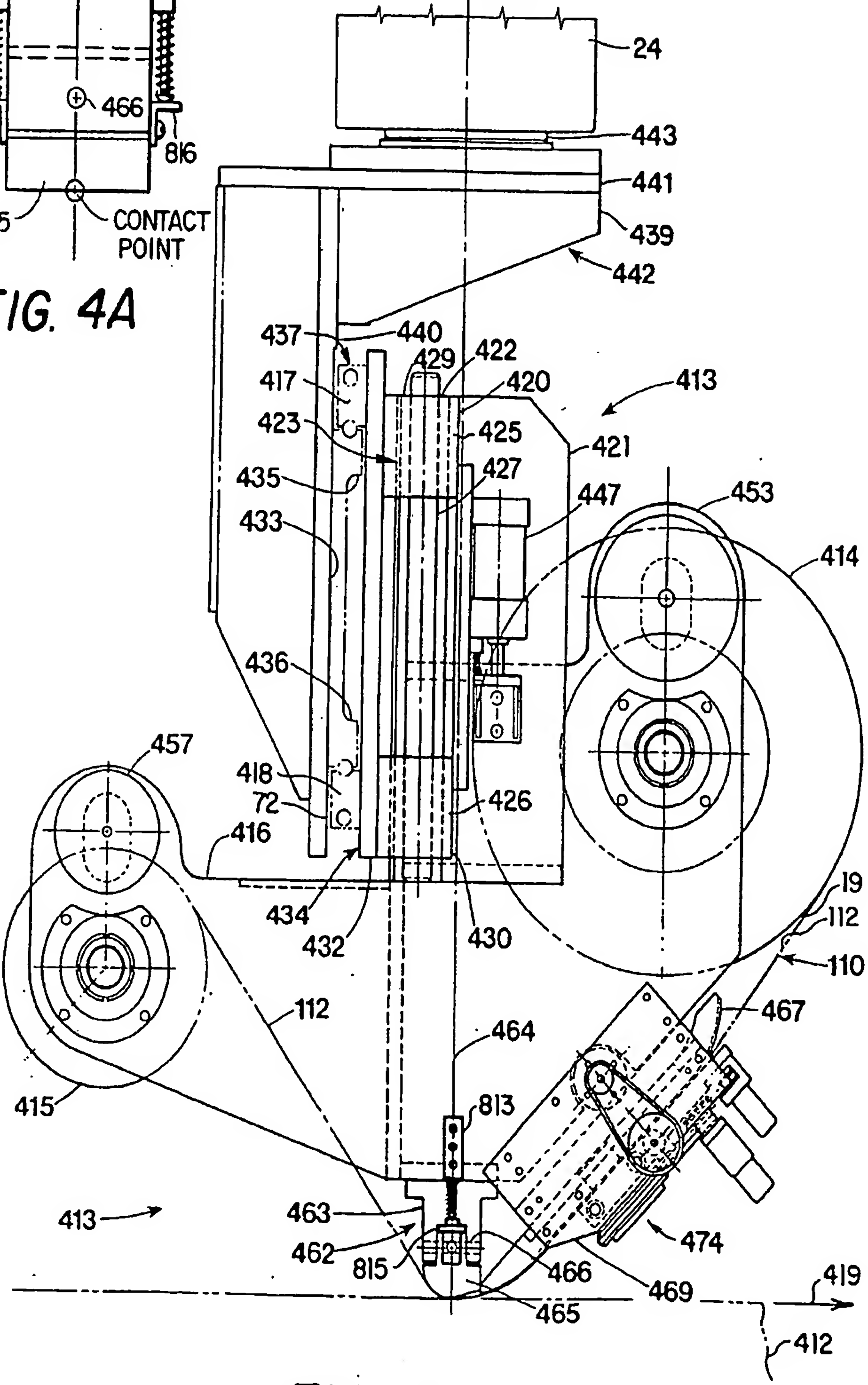
CONTACT
POINT

FIG. 4A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419
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412

FIG. 4

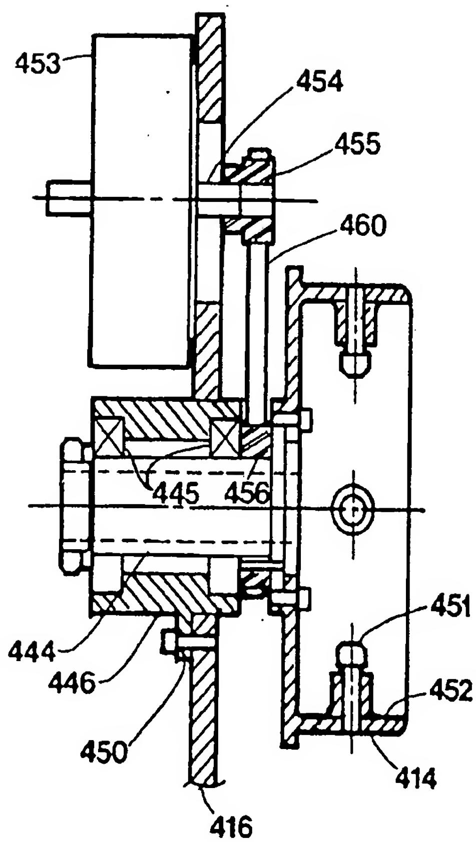
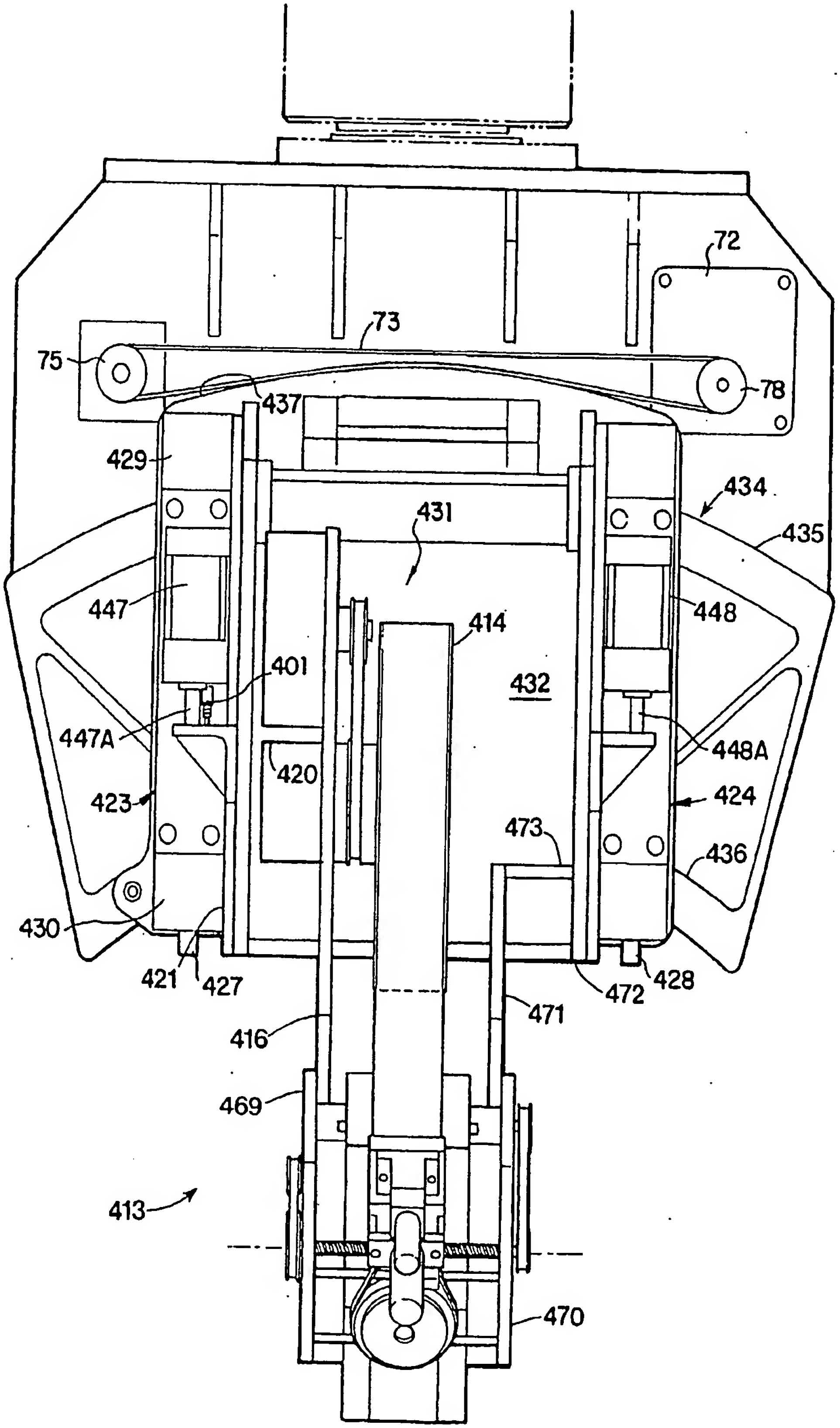


FIG. 5



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413
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FIG. 6

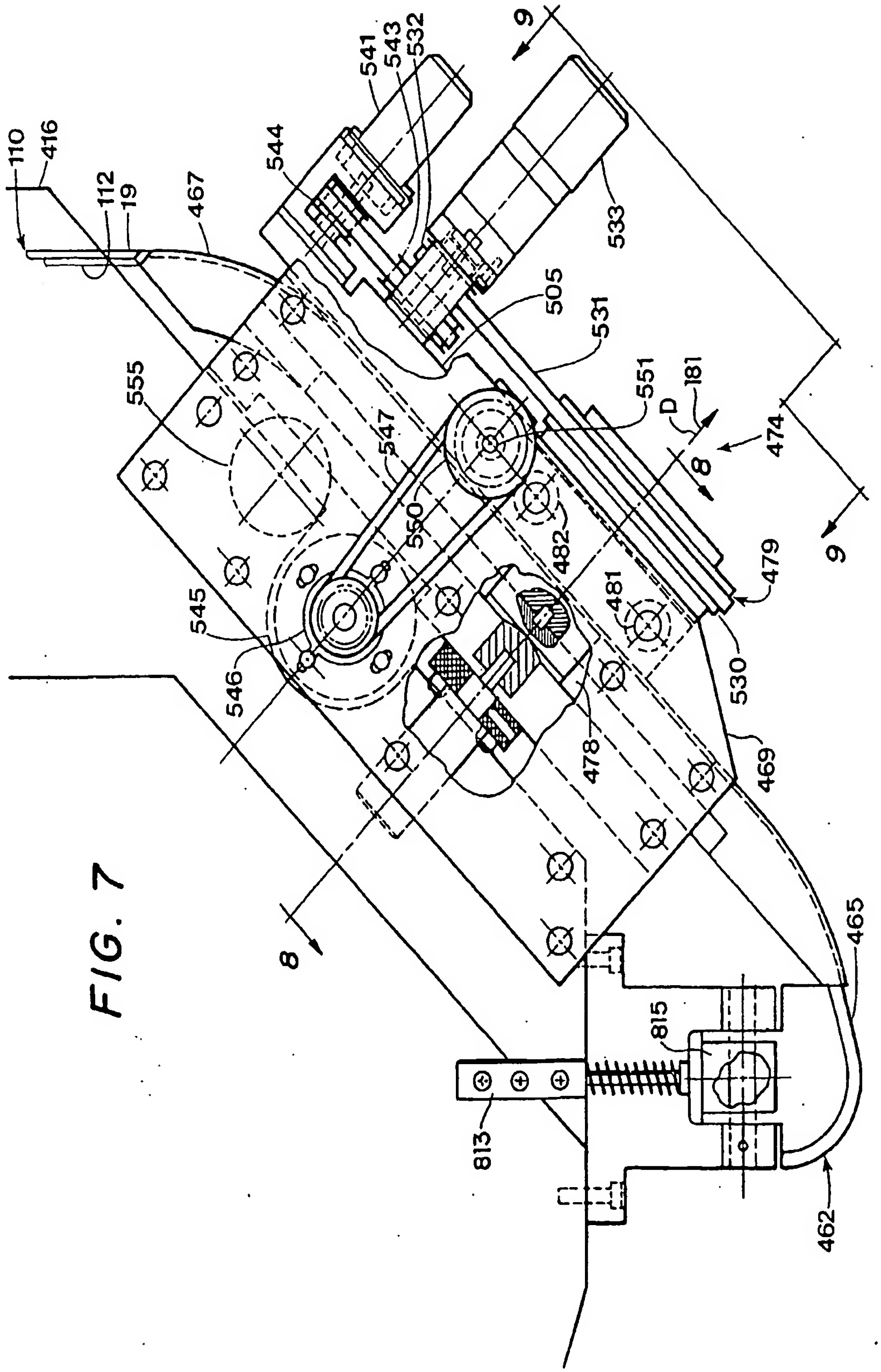
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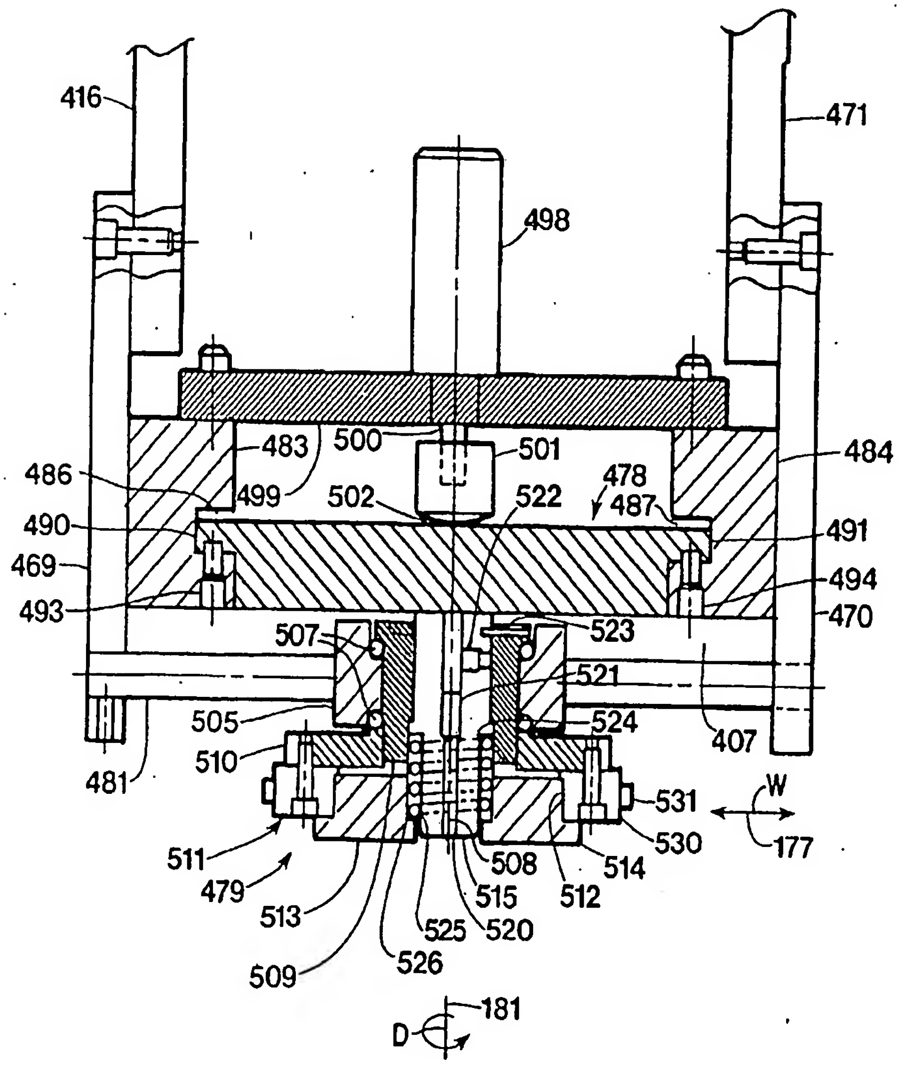
FIG. 7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407
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FIG. 8

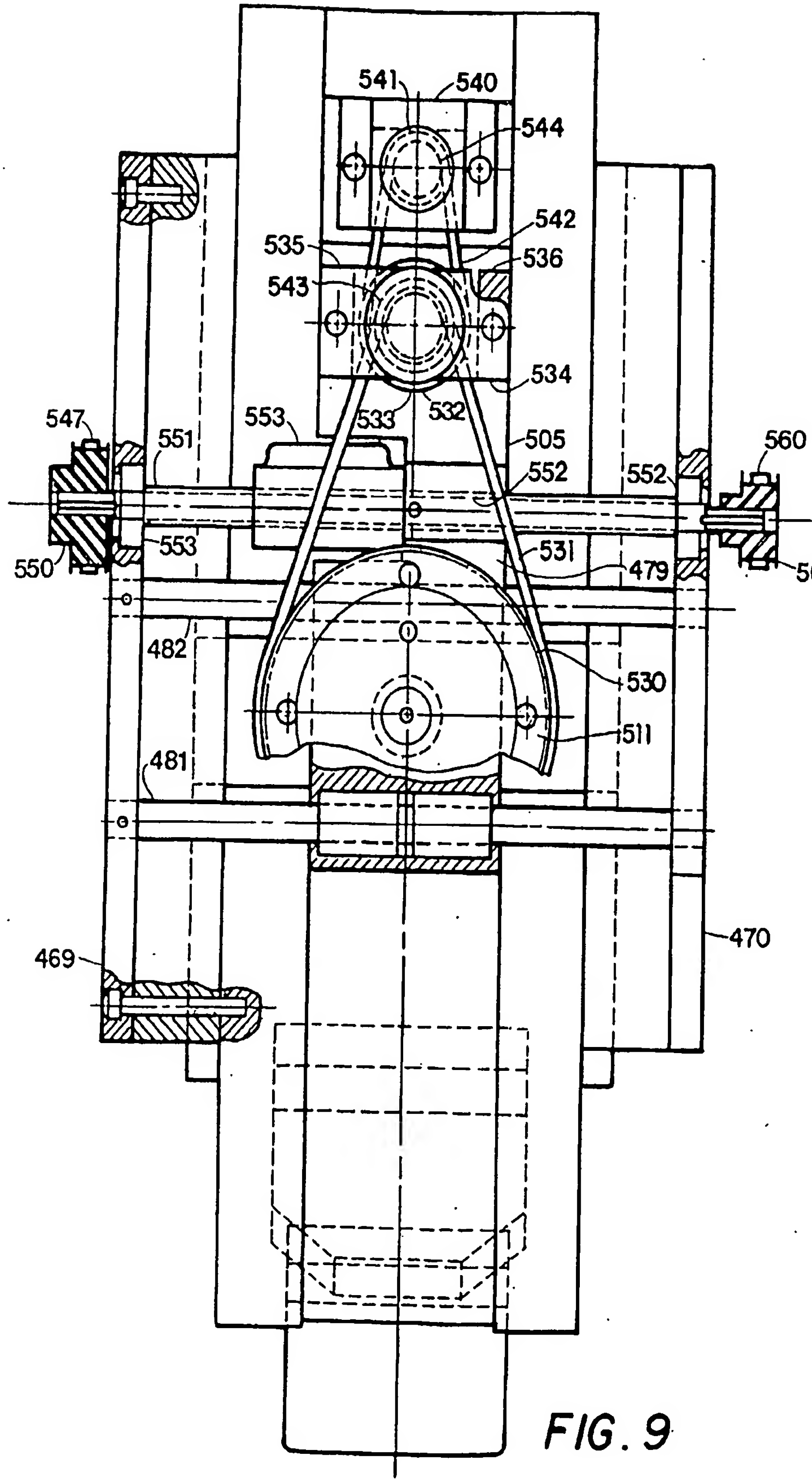
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FIG. 9

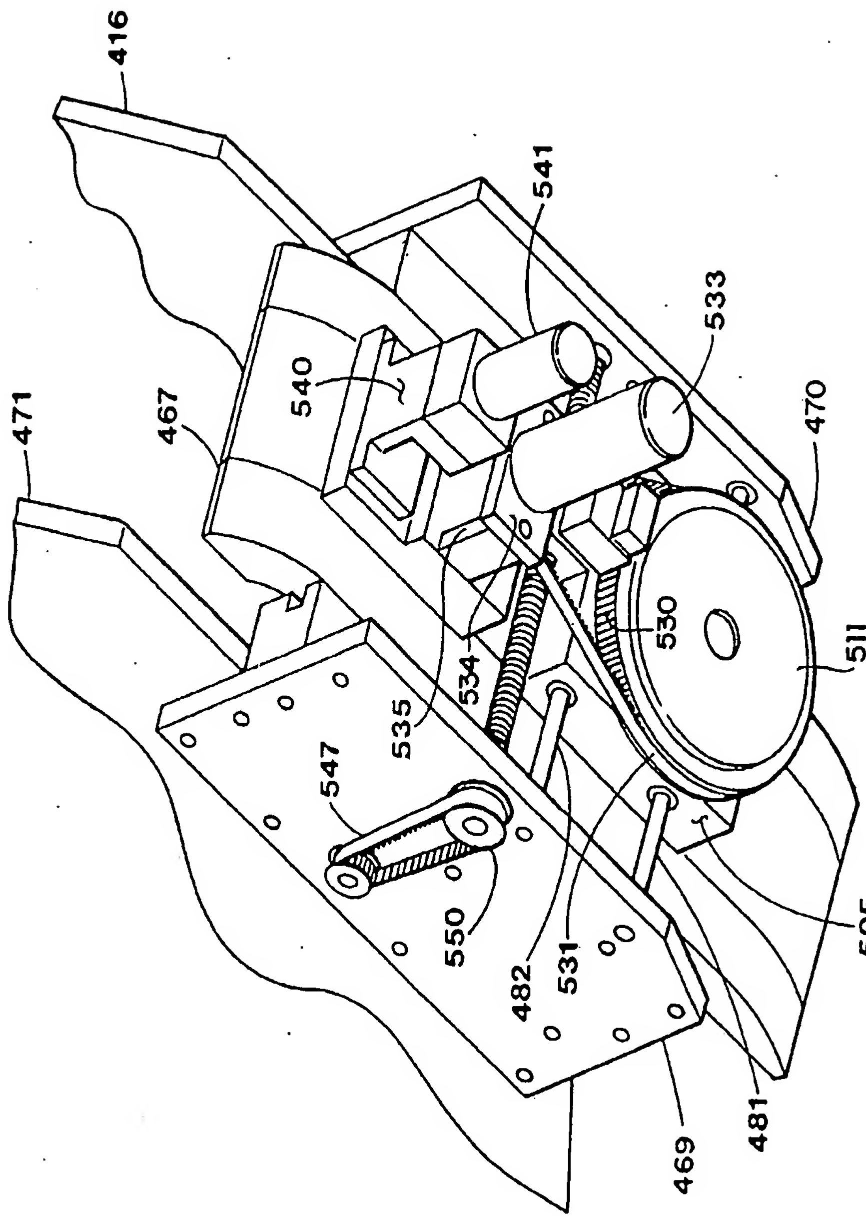
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FIG. 10

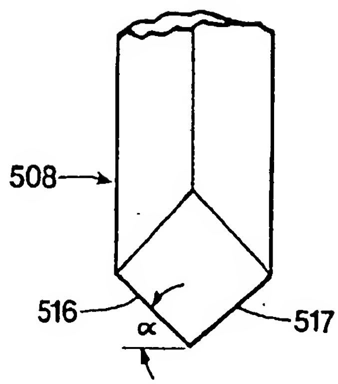


FIG. 11

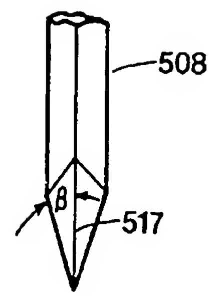


FIG. 12

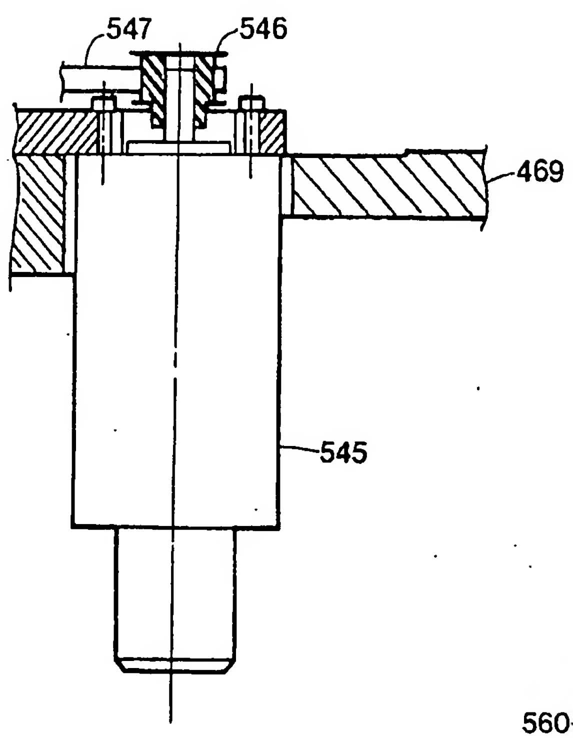


FIG. 13

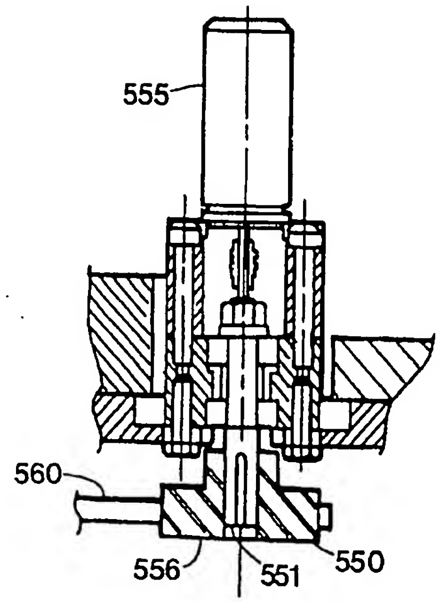
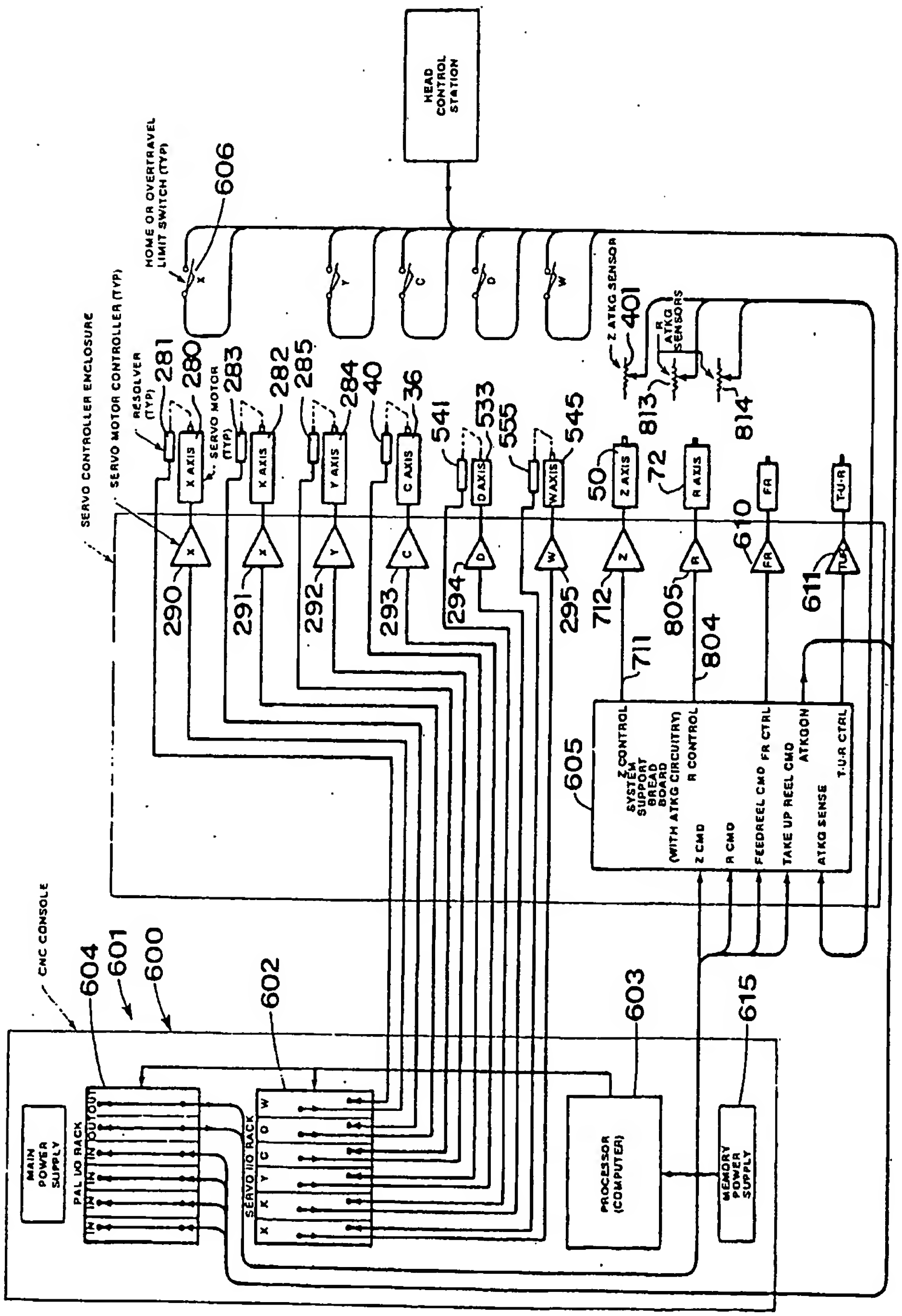
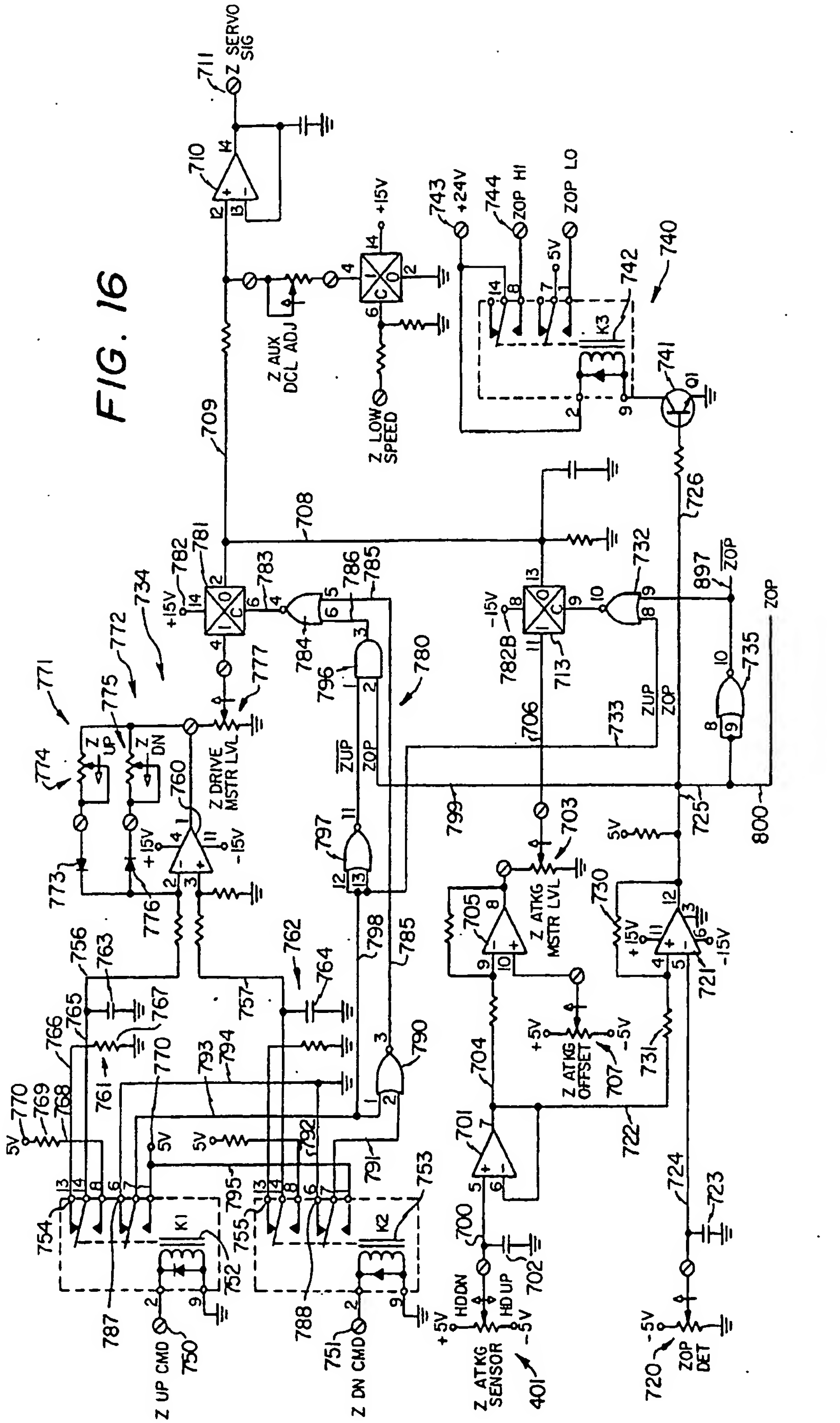


FIG. 14



HEAD CONTROL STATION
HOME OR OVERTRAVEL LIMIT SWITCH (TYP)
606
SERVO CONTROLLER ENCLOSURE
SERVO MOTOR CONTROLLER (TYP)
RESOLVER (TYP)
SERVO MOTOR (TYP)
281
280
283
282
285
284
40
36
541
533
555
545
50
72
813
814
401
Z ATKG SENSOR
R ATKG SENSORS
X AXIS
Y AXIS
C AXIS
D AXIS
W AXIS
Z AXIS
R AXIS
FR
T-U-R
290
291
292
293
294
295
712
805
610
611
711
804
605
Z CONTROL SYSTEM SUPPORT BREAD BOARD (WITH ATKG CIRCUITRY)
R CONTROL
Z CMD
R CMD
FEEDREEL CMD
FR CTRL
TAKE UP REEL CMD
ATKGON
ATKG SENSE
T-U-R CTRL
CNC CONSOLE
604
601
600
602
603
615
MAIN POWER SUPPLY
PAL I/O RACK
SERVO I/O RACK
PROCESSOR (COMPUTER)
MEMORY POWER SUPPLY

FIG. 15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Z AUX DCL ADJ
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ZOP HI
ZOP LO
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Z UP
Z DN
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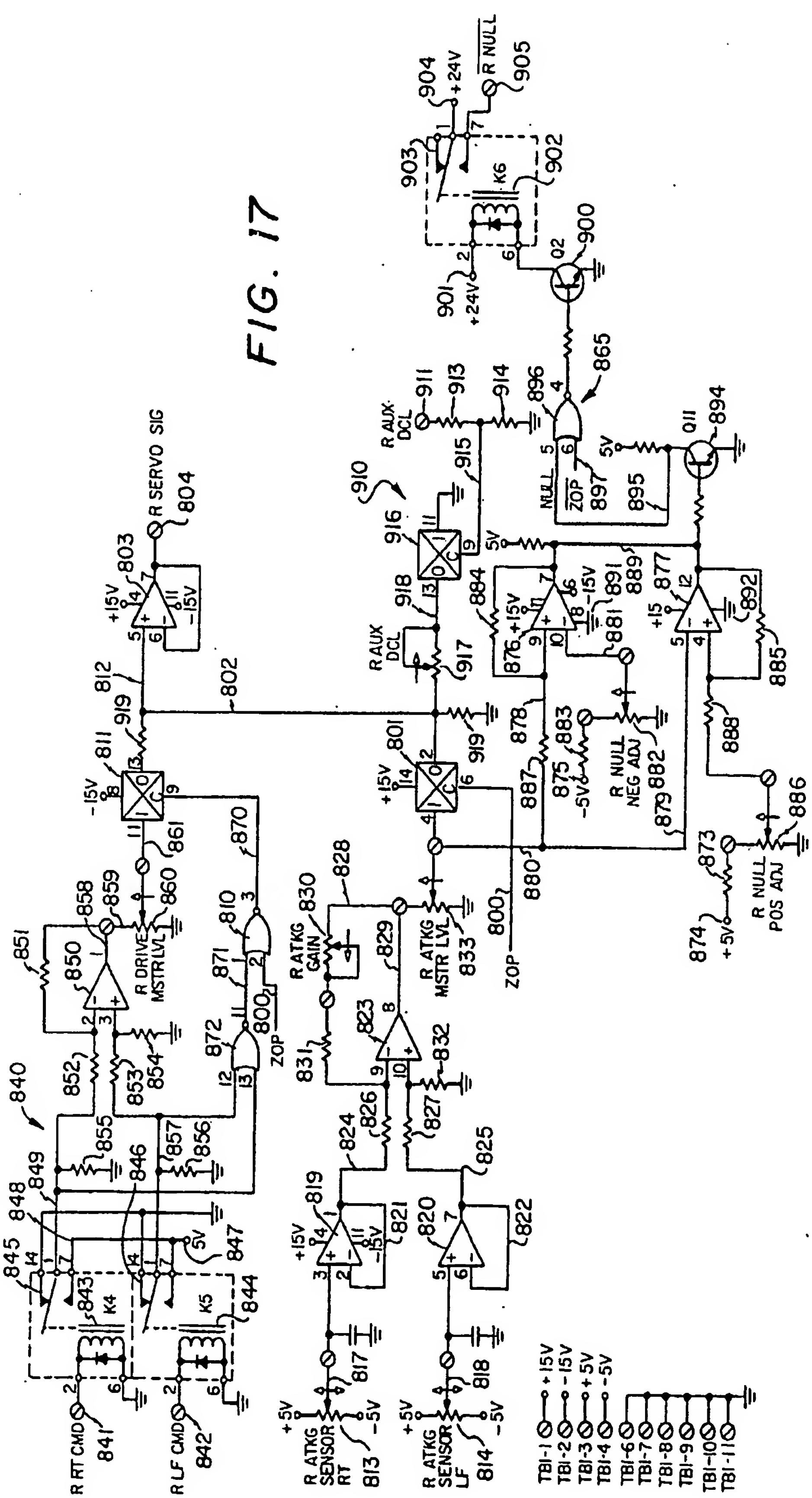
Z ATKG OFFSET
Z ATKG SENSOR
HD DN
HD UP
ZOP DET
Z UP CMD
Z DN CMD
ZUP
ZOP

FIG. 16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R RT CMD
R LF CMD
R ATKG SENSOR RT
R ATKG SENSOR LF
TB1-1 +15V
TB1-2 -15V
TB1-3 +5V
TB1-4 -5V
TB1-6
TB1-7
TB1-8
TB1-9
TB1-10
TB1-11

FIG. 17

SPECIFICATION

Method and apparatus for tape laying and manufactured composite structures

The present invention relates to apparatus and methods for tape laying on either flat or contoured surfaces and in particular to such apparatus and methods for automatic manufacturing of laminated composite structures having flat or contoured surfaces comprised of layered tape material.

Laminated composite structures are employed in a wide range of articles and devices where the light weight, high strength and the particular characteristics that can be provided for with a tape material are of benefit. Such composite structures are particularly useful in the manufacture of aircraft and other aerospace components, a variety of ground and aquatic vehicular components and in some building structural members. In many of the applications, structural members are required to sustain greater loads at particular points or along particular axes. Composite structures are well-suited to this type of service since the layers of material, e.g. tape, can be varied in number and oriented to correspond to areas of maximum strength requirements. Typically, laminated composite structures comprise a plastic matrix of a material such as an epoxy resin, reinforced with a fibrous cloth or tape-like material made from baron, graphite or fiberglass.

To manufacture laminated composite structures from tape material, there are a variety of known manufacturing methods. Many of the more commonly employed methods and the associated apparatus are cost-intensive and as a result, the only structures that are manufactured from such methods are those that can more readily bear the higher costs associated therewith. The high cost occurs because the high strength and rigidity of a tape composed of boron, graphite, fiberglass or other such fibrous materials make the tape material difficult to handle and cut in desired lengths and width. In addition, a great deal of care needs to be exercised to prevent the uncured resin of the tape material from adhering to the storage, transporting and cutting mechanisms during handling and to prevent undue resin build up on any of the surfaces of the mechanisms that continually contact the tape material. For example, a relatively simple system might employ a tape storage and transporting mechanism, and would require an operator to manually cut the tape after each required length of tape material had been drawn from the storage mechanism. The operator would then form the tape to the mold of the particular part being manufactured. Such a system is labor-intensive, very time consuming and therefore very expensive It is also vulnerable to operator errors such as creasing of the tape, improper forming of the tape into the mold, etc. There are, however, a few tape-laying systems that are more automated. U.S. Patent 4,133,711 issued to A. August, January 9, 1979 discloses a system in which successive layers of tape are laid onto a vacuum hold-down surface to form a workpiece that is then transferred to a cutting area and cut to a desired pattern by a laser cutter and finally transferred to the part mold and formed over the mold. Similarly, U.S. Patent 3,775,219 issued to H. E. Karlson et al on November 27, 1973 discloses a composite tape placement head that includes a photoelectric edge-sensing mechanism for controlling the cutting of the composite tape and automatically adjusts the path of the tape laying as necessary. Also U.S. Patent 3,970,831 issued to T. Hegyi on July 20, 1976 discloses a system for controlling a tape laying head in a plurality of axes to control tape laying onto a convexly contoured surface. The Hegyi system generates a series of control signals that are fed to the control apparatus by substituting a digitizing or detection head for the tape head and causing the digitizing head to traverse the surface of a tracing member that is disposed on the work surface of the mold. This tracing member contains sensing members that act in conjunction with the digitizing head to generate the control signals. The control signals are used to generate a program for control of the tape head during the tape laying operation. None of these systems is designed to completely manufacture a structure in the mold and to automate substantially the entire tape laying operation to avoid excess handling and to minimize operator time. Co-pending U.S. patent application Serial No. 276,441 filed June 22, 1981 by the inventors of the present invention, which application is hereby incorporated by reference herein, is believed to be the only other system that satisfactorily accomplishes these objectives. Both the present invention and the invention described in U.S. patent application Serial No. 276,441 are capable of laying tape on either a flat or contoured surface. The present invention includes an improved adaptive control system for laying tape on a contoured surface, and particularly a concavely contoured surface. This is accomplished by programming the tape laying operation along only a longitudinal X-axis, a transverse X-axis, a gross control of the vertical Z-axis (to engage or disengage the work surface only), and a rotational C-axis. Fine control of the Z-axis and a radial R-axis is accomplished by the independent, adaptive control system to be described herein. The present invention thereby distinguishes over Hegyi, since Hegyi is not adaptive to progressively layered surfaces, but rather must trace each additional tape layer with its tracing head and generate a new program after each layer of tape has been applied or become progressively more inaccurate with each layer of tape added to the work surface.

The present invention includes a number of unique features that further distinguish over the prior art. For example, in one embodiment, the tape applicator head includes a shoe member which brings the tape into contact with the mold

surface and applies an evenly distributed pressure against the tape. The position of this shoe member relative to the mold surface is continuously monitored by sensors and is continually adjustable via the adaptive control to maintain a given relationship to the mold surface. The sensors are designed to monitor the contact point between the shoe member and the mold surface and thereby signal the tape head to adjust in accordance with this contact point. In the past, sensor systems actually monitored the mold surface at a point some distance from the actual contact point due to the constraints associated with mounting the sensors. An earlier version of the present tape laying machine for example, employed electro-pneumatic sensor switches. These sensors were activated from the back pressure that resulted as the sensors came closer to the mold surface. Several such switches were mounted adjacent to roller members that applied the tape to the mold surface. While these sensors were generally reliable they could not monitor the actual point of contact between the roller members and the mold surface, thereby causing a certain amount of error in the positioning of the shoe which periodically caused uneven pressure across the roller and damage to the tape. In addition, the shoe utilized in an embodiment of the present invention in conjunction with a guide chute for guiding the tape towards the shoe, provides a means for applying pressure to the tape during the tape laying operation along the centerline of the tape. This shoe arrangement comprising the pressure applying means is a tremendous improvement over the roller members previously utilized, since rollers, due to varying frictional forces along a contoured surface, tend to slide away from the center line of the tape and may skew or damage the tape during the tape laying operation. Finally the cutter mechanism employed in an embodiment of the present invention is capable of cutting on-the-fly (i.e. while the tape head is translating across the mold surface) whereas the known prior art systems employed cutters that required the tape head to stop prior to each cut.

In addition, in order to prevent the tape from adhering to the tape laying equipment and to minimize any resin build up on the equipment, most composite tape materials are provided with a backing tape. This backing tape needs to be removed prior to application of the tape to a mold or other and, once removed, the composite tape needs to be handled carefully to avoid the problem of adhering to the equipment, and back up tape needs to be carried away. In some tape-laying systems it is necessary to separate the composite tape from the backing tape in order to cut it, then reapply the composite tape to the backing tape for application to the mold. This excessive handling of the composite tape is fraught with potential problems. For example, to reapply the composite tape to the backing tape requires the use of a heat source to soften or plasticize the tape sufficiently to readhere it.

However in other tape laying systems, while it is not necessary to remove the backing tape in order to cut the fibrous tape, it is necessary to stop the machine in order to cut the fibrous tape. The present invention avoids both of these disadvantages by employing a cutting mechanism that is capable of cutting the fibrous tape while it is still adhered to the backing tape and to cut it on the fly at all angles except perpendicular to the path of the tape.

The large size of many of the structures that are beneficially manufactured from laminated composite tape material requires the use of large supporting surfaces, curing stations and considerable space for transferring the mold and the composite tape structure between work stations. The size tends to increase the time required to manufacture composite structures since the operator must be constantly working throughout this space. As a result, the operation for manufacturing composite structures frequently includes a large degree of non-productive time.

It is therefore an object of the present invention to provide a new, improved, automated apparatus and method for manufacturing laminated composite structures.

A further object is to provide such automated apparatus to include a gantry for supporting and transporting a tape laying head that is capable of tape laying, cutting and building up of layers of tape on a mold to create a workpiece suitable for curing at a single work station.

Another object of the present invention is to provide a means for tape laying a composite tape directly from a backing tape without a requirement for separation and reapplication of the composite tape to the backing tape.

Still another object of the present invention is to provide a means for cutting tape on the fly and a means for cutting fibrous tape while it is still adhered to the backing tape.

Yet another object of the present invention is to provide a means for guiding the tape to a means for bringing the tape into contact with the mold surface such that the contact means tracks along the longitudinal centerline of the tape.

A still further object of the present invention is to provide a means for automatically laying the composite tape in layers in a mold without assistance from the operator.

A still further object of the present invention is to provide a method of manufacturing the composite structure in which trimming of the workpiece that is being formed in the mold is minimized to a single trimming operation after the tape laying operation is completed.

Another object of the present invention is to provide an operator programmable apparatus that can be controlled with a relatively simple program, such as would be used for tape laying on a flat surface, and that is fully capable of tape laying on a complex, contoured surface.

It is yet another object of the Invention to provide a tape laying machine which is adaptive

to a contoured surface for evenly applying pressure against the tape in progressive layers as the layers are formed on a contoured mold or fixture surface.

It is still another object of the present invention to provide a method whereby a workpiece can be formed, trimmed and cured while still in the mold, thereby minimizing handling of the composite tape material comprising the workpiece.

And, it is still a further object of the present invention to provide an apparatus capable of performing the objects stated above while at the same time being reliable and economical as compared to prior-art systems.

Disclosure of the invention

Brief description of the invention

These and other objects are accomplished in accordance with the present invention in which an apparatus for manufacturing a structure from layered composite tape material formed on a mold having a work surface corresponding to the structure comprises a first means for containing and dispensing the tape and a second means for translating the first means across the work surface. In one embodiment, the first means is operable for applying the tape onto the work surface while being translated across the work surface and includes orienting means, means for contacting the work surface and sensing the contour thereof as it is translated across the work surface, and a signaling means responsive to the contour sensing means for providing signals to the orienting means indicative of the sensed changes in contour with respect to the orientation of the first means. The orientation means is responsive to the signals thus provided by the signaling means for altering the orientation of the first means such that a pressure applying member of the first means is positioned substantially normal to said work surface. In a further embodiment of the invention, the pressure applying member is a shoe which is additionally coupled to the sensor means for contacting the contoured tape surface for the sensor means.

Brief description of the drawings

Further objects and advantages of the invention will be apparent from the specification and claims and from the accompanying drawings, wherein:

Figure 1 is a perspective view of an embodiment of a tape laying machine in accordance with the present invention showing a contoured mold and partially formed workpiece.

Figure 2 is a cross-sectional view of the tape laying machine of Figure 1 taken along lines 2—2 of Figure 1.

Figure 3 is an enlarged perspective view of the tape applicator head assembly that is employed with the tape laying machine of Figure 1.

Figure 4 is a side view of the tape applicator head assembly of Figure 3 taken from the left side as indicated by lines 4—4.

Figure 4a is a front view of the shoe member of the tape head showing the R-axis sensors.

Figure 5 is a cross-sectional view of the supply reel employed on the tape head assembly of Figure 3 taken along lines 5—5.

Figure 6 is a front elevational view of the tape head assembly of Figure 3.

Figure 7 is an enlarged, fragmentary, side elevational view of the cutter mechanism employed in the tape applicator head assembly of Figure 3 as indicated by lines 7—7.

Figure 8 is a cross-sectional view of the cutter mechanism of Figure 7 taken along lines 8—8 to show the styles and the stylus housing assembly.

Figure 9 is a front elevational view, enlarged in scale and partially broken away, of the cutter mechanism of Figure 7 viewed as indicated by lines 9—9.

Figure 10 is a perspective view of the cutter mechanism of Figure 7 showing it mounted to the tape guide of the tape applicator head of Figure 3.

Figure 11 is a fragmentary, front elevational view of the stylus cutter of the cutter mechanism of Figure 7.

Figure 12 is a fragmentary, side elevational view of the stylus cutter of the cutter mechanism of Figure 7.

Figure 13 is a cross-sectional view of the W-axis motor and its associated components.

Figure 14 is a cross-sectional view of the W-axis resolver and its associated components.

Figure 15 is a block diagram representation of the automatic control system for the tape laying machine.

Figure 16 is a diagrammatic representation of the Z-axis control circuit for independently controlling the Z-axis movement of the tape applicator head during the tape laying operation.

Figure 17 is a diagrammatic representation of the R-axis control circuit for independently controlling the R-axis movement of tape applicator head during the tape laying operation.

Detailed description of the invention

Referring now to the drawings in detail, wherein like numerals indicate like elements throughout the several views, in Fig. 1, tape laying machine 410 is shown including a gantry 11 extending over a mold or work table 412. Gantry 11 includes means, to be described in detail, movably supporting a tape applicator head assembly 413. First and second tracks or ways 14, 15 are positioned in mutually parallel alignment extending perpendicularly of gantry 11 on either side of work table 412. Movement of tape applicator head 413 along gantry 11 relative to work table 412 is denoted by movement along the "Y-axis," and movement in the direction parallel to tracks 14, 15 is termed "X-axis" movement. For convenience, tracks 14, 15 are termed herein the left and right, "X-axis tracks". Gantry 11 includes an elongated beam 16 of generally rectangular cross section supported at its end portions by left and right gantry pedestals 17, 18 which are movably supported on the tracks 14, 15 by means of internal rollers, not

shown, suitably of the type known in the art as Thompson round way rollers, whereby the pedestals may be translated along the X-axis tracks. Movement of the gantry along X-axis tracks 14, 15 and/or movement of tape laying head assembly 413 along gantry beam 16, when tape applicator head assembly 413 is in contact with the work table or the surface of mold 412, results in the dispensing of lengths of the fibrous composite tape 19 from tape applicator head assembly 413, and in the placement and adhering of the tape to the work surface of mold 412 along a desired path of the X and Y axis, as will be disclosed in the description to follow of tape head assembly 413.

Referring to Fig. 2, gantry beam 16, in a preferred embodiment, includes upper and lower Y-axis tracks 20, 20' extending longitudinally of and mounted on the beam, on its upper and lower sides, respectively. A gantry saddle assembly 21 is provided for mounting tape head assembly 413 below gantry beam 16 for permitting movement of tape head assembly 413 along gantry beam 16. Gantry saddle assembly 21 is of generally rectangular cross-section, adapted to receive gantry beam 16, and includes upper and lower roller assemblies and tracks 22, 22' adapted to movably engage upper and lower Y-axis tracks 20, 20', respectively. The construction of such roller assemblies and tracks 20, 20' is known to those in the art and will not be described in further detail herein.

Tape laying head 413 is rotatably mounted to Y-axis saddle assembly 21 by a mounting yoke structure 23 which encloses a dual bearing assembly 24, in which a vertical shaft 443 is rotatably journaled for permitting rotation of the shaft 443 about a substantially vertical axis 444, termed herein the "C" axis. Bearing assembly 24 and shaft 443 are termed the "C-axis" bearing assembly and the "C-axis" shaft, respectively. A double reduction gear drive system 27 is preferably employed for effecting controlled rotation of C-axis shaft 443 and tape head assembly 413 about the C-axis 444. Reduction drive system 27 includes a first timing wheel 28 coaxially mounted and splined to C-axis shaft 443 and engaging a first timing chain 30, which also engages a second, smaller timing wheel 31 mounted on a vertical shaft 32 rotatably mounted within yoke structure 23. A third timing wheel 33 is also coaxially affixed to shaft 32 and engages a second timing chain 34 extending outwardly from yoke structure 23 to engage a fourth timing wheel 35, smaller than the third timing wheel 33. A "C-axis" DC drive motor 36 is mounted on an extension of yoke structure 23 and is drivingly engaged to fourth timing wheel 35, for effecting controlled rotation of tape head assembly 413. A position sensing feedback transducer 40, capable of generating a signal corresponding to the rotational position of the C-axis shaft, is driven by C-axis drive motor 36 for providing an electrical output signal corresponding to the degree of rotation of the motor shaft, whereby the C-axis position of tape head assembly 413 may be monitored and controlled by a control means, to be henceforth described in detail.

Tape laying head assembly 413 includes a supporting framework 442, shown more clearly in Figures 3 and 4, which is non-rotatably connected to and depends from a portion of C-axis shaft 443 extending downwardly from C-axis bearing structure 24.

Translation of tape head assembly 413 vertically or in the "Z" axis as shown in Figure 2 is accomplished by a Z-axis drive mechanism 41 which includes a threaded drive shaft 42 that extends downwardly from bearing support 43 mounted on a vertically extending slide plate 44 affixed to a side portion of Y-axis saddle 21 and extending upwardly, along the Y-axis, from sadde 21. Z-axis threaded drive shaft 42 extends downwardly within a housing 45, to which tape head mounting yoke structure 23 is affixed, and drive shaft 42 is threadingly engaged within corresponding internally threaded block members 46, 47 mounted within Z-axis housing 45. Threaded shaft 42 is driven by a timing belt, not shown, that are engaged with a Z-axis DC servomotor 50 that is mounted on Z-axis slide plate 44. A position sensor 51 is mounted on drive motor 50 for generating position feedback signals corresponding to the degree of rotation of drive motor 50 and threaded drive shaft 42. Rotation of threaded drive shaft 42 within internally threaded blocks 46, 47 results in vertical movement of housing 45 upon shaft 42 and thus, in vertical displacement of tape applicator head assembly 413.

Referring again to Figures 3 and 4, tape head assembly 413 is shown to comprise a tape transporting and cutting mechanism 474. Tape head assembly 413 is similar to the tape head 13 disclosed in co-pending application, serial number 276,441 filed June 22, 1981, which application is incorporated by reference herein. Tape cutting mechanism 474 is designed such that fibrous tape 19 is severed while still affixed to backing tape 112 and "on-the-fly", i.e. while tape head 413 continues to move across mold surface 412, and a portion of the tape is applied to the work surface of mold structure 412 subsequent to being cut within transport mechanism 474. Whereas in certain existing tape laying machines, the fibrous tape must be separated from the backing tape by means of a splitter wedge or knife directioned toward the interface between the fibrous tape and backing tape in order to permit cutting of the fibrous tape without scoring and weakening the backing strip; the present cutting mechanism does not require that fibrous tape 19 be separated from backing strip 112 during cutting operations. Cutting mechanism 469 therefore eliminates the difficulties entailed in such prior art procedures, such as the necessity of separating the adhesive tape from the backing strip and subsequently readhering the tape to the backing strip prior to laying of the tape, and the consequent difficulties entailed. In certain prior-

art systems, for example, it has been required to heat the fibrous tape stripped from the backing strip in order to plasticize its resin to permit readherence of the tape to the backing strip. Deleterious effects of such processes may include distortion to the fibrous tape through the separation process, and premature curing or stiffening of the tape through this heating process wherein satisfactory readherence of the fibrous tape to the backing strip, and adherence of the tape to the mold, may not be obtained.

Continuing to refer to Figs. 3 and 4, tape head supporting framwork 442 includes a vertical backplate or stiffback plate 440 extending downwardly from a horizontally extending top plate 441 affixed to shaft 443, vertical flanges 439 being welded or otherwise affixed to and extending horizontally between backplate 440 and top plate 441, and rear flanges extending downwardly along the opposite or rear side surface of the backplate, for reinforcing framework 442. Tape head assembly 413 includes left and right face or side plates 421, 422, rigidly connected in parallel, mutually spaced relation by bracket 438 extending between and bolted to plates 421, 422. Side plates 421, 422 serve as a supporting frame of tape head mechanism 413, to be more fully described hereinbelow.

Tape head assembly 413 is pivotally connected to back plate 440 by an R-axis mounting assembly 433 (Fig. 3) permitting rotational displacement of head assembly 413 about an R-axis 419 (Fig. 4). R-axis 419 is aligned with tape head assembly 413 and when tape head assembly 413 is aligned with the X-axis as shown in Figs. 1, and 2, extends parallel to the X-axis and centrally intersects tape head assembly 413 adjacent its lowermost portion, i.e., at its intersection with mold structure 412. R-axis mounting assembly 433 includes an R-axis track framework 434 including upper and lower arcuate bars or tracks 435, 436, (shown more clearly in Figures 3 and 6) concentric with R-axis 419. Tape head assembly 413 has a rigid mounting plate 432 (Fig. 4) having upper and lower recirculating ball bearing assemblies 417, 418, adapted to mate with upper and lower arcuate tracks 435, 436, respectively, for permitting arcuate movement of mounting plate 432 relative to upper and lower tracks 435, 436 and thereby permitting arcuate movement about R-axis 419 of tape head assembly 413. Counterbalancing pneumatic actuators 447, 448 as shown, are employed to apply an upward force against assembly 413 sufficient to leave a desired degree of pressure on tape structure 110 as it is being applied to the mold surface, as previously detailed.

An R-axis drive mechanism 71, Fig. 6, includes a DC servomotor 72 mounted on backplate 440. An R-axis timing belt 73 connected to a driving pulley 78 on motor 72, extends along backplate 440 over and in engagement with an arcuate, driven surface 437 of mounting plate 432, and is looped around a corresponding pulley 75 mounted on the opposite side of backplate 440 in alignment with surface 437 and drive motor 72. Rotation of drive motor 72 in a clockwise direction, as viewed in Fig. 6, causes leftward movement of the lower section of timing belt 73 and thereby affects counterclockwise arcuate movement of mounting plate 432 and tape head assembly 413, upon upper and lower tracks 435, 436.

Referring back to Fig. 3, tape head frame structure 431 is connected to mounting plate 432 by means of left and right, vertical bushing assemblies 423, 424. With additional reference to Fig. 4, left bushing structure 423 includes upper and lower, recirculating linear ball bushing assemblies 425, 426 which are bolted or otherwise affixed to mounting plate 432. Referring again to Fig. 3, left and right, upper bushing assemblies 425, 425' are movable vertically relative to left and right vertical shafts 427, 428 which are axially movably received within linear bushing assemblies 425, 425'. As seen in Fig. 4a, bushing assemblies 425, 425' are semi-enclosed, and in cross section have inwardly-facing, vertically extending slots for receiving left and right shaft mounting brackets 458, 459 which are bolted to left and right shafts 427, 428, respectively. Mounting brackets 458, 459 are also bolted or otherwise affixed to left and right side plates 421, 472, respectively. In operation, shafts 427, 428, mounting brackets 458, 459, and tape head framework 431 are thus movable vertically relative to mounting pate 432 by means of vertical movement of the shafts 427, 428 within the bushing assemblies for accommodating minor vertical movements of the tape head 413.

With reference to Fig. 6, left and right pneumatic actuators 447, 448 are connected to left and right bushing structures 423, 424, and extend downwardly alongside left and right side plates 421, 472. Respective, left and right actuator rods 447A, 448A, are connected to side plates 421, 472 by means of brackets mounted to the rods and affixed to the left and right side plates. Air under pressure is applied to the lower chambers of actuators 447, 448, during operation which tends to counterbalance, or exert an upward force, on tape head assembly 413 for controlling the pressure of head assembly 413 upon mold surface 412. Servocontrol means are provided for sensing the vertical position of tape head frame 431 relative to mounting plate 432 and for actuating Z-axis drive motor 50 to raise or lower tape head 413 and mounting yoke 23, to maintain actuator rods 447A, 448A approximately centered within their range of movement within actuators 447, 448. Actuators 447, 448 and associated components thus comprise a means for controlling the degree of pressure exerted upon composite tape 110 by opposing to a predetermined degree the downward force produced by the weight of tape head assembly 413.

With reference to Fig. 4, tape head assembly 413 includes a tape supply and feed reel 414 and a takeup reel 415, both mounted on a rigid mounting plate structure 416. Composite tape structure 110 contained in feed reel 414 comprises pre-impregnated fibrous tape 19 and a backing strip 112. Fibrous tape 19, for example, is a tape of suitable width formed for undirectional graphite fibers, impregnated with an uncured epoxy resin. Backing strip 112, for example, may suitably be of waxed paper of 60—80 pounds per thousand square feet. The tape structure is suitably formed on cardboard spools not shown. Referring additionally to Fig. 6, plate structure 416 is affixed in parallel relationship, as by flanges 420, to a left, vertical support plate 421 which is affixed to left vertical shaft 427 (Fig. 4) longitudinally slideable within upper and lower linear bushing assemblies 429, 430, which in turn are affixed, in vertical alignment, to a backing plate 432.

R-axis movement of tape head assembly 413 is permitted about an arcuate framework 434 (Fig. 6) defining upper and lower arcuate tracks 435, 436, which is affixed to a mounting or backplate 440 (Fig. 4). Backplate 440 depends from a horizontally extending top plate 441; top plate 441, backplate 440, and associated structure comprising a tape head supporting framework 442. Entire framework 442 and tape head assembly 413 are fixed to a downwardly extending shaft 443 rotatable about a vertical, C-axis 444.

Referring to Fig. 5, supply reel 414 is mounted to plate structure 416 upon an axle or shaft 444 rotatable within a bearing assembly 445 seated with a cylindrical bearing assembly housing 446, and extending perpendicularly of plate structure 416. Bearing housing 446 includes flanges 450 for permitting the housing to be bolted or otherwise affixed to plate structure 416. Supply reel 414 is in the form of a hub, open in a direction facing outwardly from plate structure 416, permitting convenient loading of a spool of tape over the cylindrical hub portion as indicated at 452. This configuration is appropriate for this embodiment of the apparatus because the guide chute and cutting mechanism maintain the tape in alignment with supply reel 414 and take-up reels 415 and centered relative to shoe 465. Lock screws 451 are provided extending radially outwardly through the hub for permitting securing of a spool of tape upon reel 414. A servomotor 453 is mounted to plate structure 416 above takeup reel 414, the servomotor having a drive shaft 454 which projects through an opening formed through plate structure 416. Mounted on the projecting portion of shaft 454 is a timing pulley 455 positioned in lateral alignment with corresponding pulley 456, which in turn is coaxially mounted upon a shaft 444 between takeup reel 414 and bearing assembly housing 446, for rotation with shaft 444. Drive belt 460 engages pulleys 455 and 456 for applying a counterclockwise torque, as viewed in Fig. 4, to takeup reel 414. Referring to Figure 4, supply reel 414 mounted on plate structure 416 is suitably positioned in approximate horizontal alignment with mounting plate 432 (Fig. 4) along the normally forward or leading portion of plate structure 416, and takeup reel 415; and a corresponding takeup reel motor 457, is mounted along the upper, rear portion of plate structure 416.

Continuing to refer to Fig. 4, applicator shoe assembly 462 is mounted to plate structure 416 at its central, lower portion, shoe assembly 462 having a downwardly projecting mounting block 463 mounted on plate structure 416 by horizontally extending bolt 464, the mounting block having a longitudinal slot, extending perpendicularly of the plate structure and open downwardly, for receiving applicator shoe insert 465 of a low friction material such as Teflon ("RTM"), having an arcuate, convex lower cross-sectional surface. Bolt 466 having a stepped threaded end portion of reduced diameter is extended through mounting block 463, suitably of aluminum, and insert 465 and is engaged within a stepped bore formed in block 463 for permitting limited rocking movement of shoe 465 about the axis of bolt 466 (not shown) to accommodate irregularities in mold surface 412. Guide chute 467 is mounted between plate structures 416, 471 (Figure 6) in alignment with supply reel 414 and applicator shoe 465. The movement of shoe 465 about 466 is detected, as shown in Figure 4a by linear potentiometer sensors 813 and 814 mounted on flanges 815 and 816 that are connected to the left and right side, respectively, of shoe 465. In operation tape structure 110, consisting of fibrous tape 19 and the backing strip 112 is guided toward applicator shoe 465 by guide chute 467 after passing through the cutting device and thereby ensure that shoe 465 tracks along the longitudinal centerline of tape 110. With reference to Fig. 6, a left cutter assembly mounting plate 469 is affixed to the outer surface of plate structure 416 and, as seen in Fig. 4, mounting plate 469 extends along the side of plate structure 416 between supply reel 414 and applicator shoe 465. A corresponding, right mounting plate 470 (fig. 6) is affixed to plate structure 471 which extends in parallel to first major plate structure 416. Plate structure 471 is affixed to right vertical support plate 472 by means of flanges 473, the right vertical support plate being affixed to backplate 432. With reference to Fig. 7, left cutter assembly mounting plate 469 is bolted or otherwise suitably affixed to plate structure 416 for supporting cutter assembly 474. Tape structure 110 comprising fibrous tape 19 and backing tape 112 is conducted along the chute track through cutter mechanism 474 to applicator shoe assembly 462 between an anvil structure 478 and a stylus housing assembly 479. Referring to Fig. 8, stylus housing assembly 479 is slideably mounted on first guide rod 481, and as shown in Fig. 9, second guide rod 482 parallel to the first, the

guide rods 481, 482 extending along W-axis 177 between and connected to the left and right cutter assembly mounting plates 469, 470.

Anvil 478 (Fig. 8) comprises a rectangular plate structure having left and right projecting flanges 490, 491. Left and right, elongated guide blocks 483 and 484 and affixed to left and right cutter assembly mounting plates 469, 470, respectively, and extend parallel to and immediately above the guide chute 467 (Fig. 7) along the path of tape structure 110. Mounting blocks 483, 484 have respective longitudinally extending grooves 486, 487 extending along their length, cut into the inwardly facing surfaces of guide blocks 483, 484. Left and right flanges 490, 491 of anvil 478, in use, project within the grooves 486, 487 of mounting blocks 483, 484 and are, in vertical cross-sectional width somewhat less than the width of rectangular slots 486, 487, whereby anvil 478 is free to move to a limited degree in the vertical direction within slots 486, 487. Left and right coiled spring assemblies 493, 494 are seated within corresponding bores formed vertically through the mounting block structures 483, 484, respectively, and project upwardly into contact with the lowermost surface areas of flanges 490, 491. Spring assemblies 493, 494 have plungers biased against the flanges that urge anvil structure 478 upwardly within grooves 486, 487. An actuator 498, either electromagnetic or pneumatic, is mounted upon a mounting plate 499 adjacent and above anvil 478. Mounting plate 499 extends between and over left and right mounting blocks 483, 484 and is bolted to their upper surfaces, respectively, for rigidly positioning actuator assembly 498 is place. Actuator assembly 498 includes plunger 500 which extends downwardly from mounting plate 499 toward anvil 478, plunger 500 having a generally cylindrical cam member 501 with a semi-spherical cam surface 502 facing the upper surface anvil 478 for exerting downward pressure against anvil 478 in response to pressure applied by plunger 500 of actuator 498. Accordingly, anvil 478 is urged downwardly by actuator 498 into contact with upwardly facing side surfaces of grooves 486, 487 when power is applied to actuator 498, and is urged upwardly by spring assemblies 493, 494 when power is reduced within actuator 498.

Alternatively, anvil 478 could be eliminated by combining it with guide chute 467. The extended guide chute would eliminate the need for mounting blocks 483, 484, grooves 486, 487, flanges 490, 491, springs 493, 494 and cam member 501. The extended guide chute would be provided with a special anvil surface, however, and stylus housing 479 would be urged upwardly, as viewed in Figure 8 by an actuator mounted on cap member 513 to bring stylus 508 into contact with the special anvil surface.

Referring additionally to Fig. 9, stylus housing assembly 479 includes a carriage block 505 having bores for slidably receiving the guide rods 481, 482, mounting carriage 505 extending longitudinally between left and right mounting plates 469, 470. Referring back to Fig. 8, mounting carriage 505 is adapted to rotatably receive stylus assembly carriage 479 within D-axis bearing assembly 507. Referring to Fig. 10, stylus housing assembly carriage 505 is slideably mounted on first and second, mutually parallel guide rods 481, 482, connected between left and right cutter assembly mounting plates 469, 470, and extending along W-axis 177 (Fig. 8) for permitting slideable movement of carriage 505 and stylus housing assembly 479 along the W-axis 177.

Stylus housing assembly 479 includes several components which are mutually affixed for rotation within bearing assembly 507 and for positioning stylus 508 in contact with fibrous tape 19. With reference to Fig. 8, these include a generally cylindrical sleeve member 509 which is rotatably mounted within bearing assembly 507 for rotation about D-axis 181. Sleeve member 509 extends downwardly beyond the carriage 505, and its projecting portion is coaxially affixed within annular plate 510 which extends radially outwardly, below carriage 505. Ring member 511, of rectangular local cross section, is bolted to the lower surface of the annular plate 510, coaxially of the plate, and its inner cylindrical surface is provided with threads 512. An annular cap or insert member 513 is threadingly engaged within ring member 511, and its lowermost portion is extended radially as an outwardly projecting, annular flange 514, which projects beyond ring member 511 and limits the rotation of the cap member within the ring member. As shown in Fig. 11, stylus, 508, in front elevation, preferably comprises a cutting knife having first and second cutting edges 516, 517. In our experiments we have found that the angle of attack, i.e., the angle defined by the leading cutting edge of the stylus and the plane of the tape is preferably approximately 40°, and it is preferably within plus or minus 5 percent of 40 degrees, i.e., from 35 to 45 degrees, and may fall within the range of 30 to 50 degrees. This angle is selected to effect cutting of the longitudinal fibers within tape 110. In the side view (Fig. 12), stylus 508 tapers to the cutting edge and includes relief angles B of approximately 15° from the center to the sides of the cutting knife. Configurations substantially different from the above, having cutting angles greater than 50 percent, have been found to distort and push aside the strands of tape rather than severing them. If the angle of the cutting edge of the knife is reduced, the knife tends to ride above the tape rather than completely severing the strands.

Referring to Fig. 8, stylus 508 is carried within an elongated, cylindrical stylus carriage 515, the stylus carriage having bore 520 formed coaxially therethrough for receiving stylus 508, bore 520 having internal threads for receiving a positioning set screw 521 which is employed for longitudinally positioning stylus 508 within bore 520. A laterally extending set screw 522 is

threadingly engaged within a bore formed radially through a sidewall of stylus carriage 515 for rigidly positioning stylus 508 at a desired position within stylus carriage 515. In operation, stylus 508 is positioned such that its cutting edge projects beyond stylus carriage 515 for a sufficient distance to scribe and sever fibrous tape 19 during W-axis movement of carriage 505 and stylus housing assembly 479, but stylus 508 is not permitted to project sufficiently to damage or sever backing strip 112. The position of stylus 508 within carriage assembly 505 is adjusted most accurately by empirical testing on the particular tape structure to be employed, in that the thicknesses, plasticity, material structure, and resins of composite tapes may vary from lot to lot, and thus may exhibit differing cutting characteristics in actual use. Typically, however, the appropriate projection of the stylus tip beyond the carriage has been found to correlate with of the thickness of fibrous tape 19. Stylus carriage 515 is itself splined to sleeve member 509, for preventing relative rotational movement between the two elements, by pin 523 which is extended through a bore formed radially through sleeve 509, and within a corresponding longitudinally extending groove formed in the side of the stylus carriage 515. The lower portion of stylus carriage 515 is of a reduced diameter, having a downwardly facing, radially extending seat 524 at its mid-portion. The upper portion of the cap or insert member 513 is also of a reduced diameter, defining an upwardly facing seat 525. Coil spring 526 is mounted coaxially of the reduced diameter portion of stylus carriage 515, and its ends are footed against seats 524, 525 for urging stylus carriage 515 upwardly within sleeve member 509.

In use, the cutting force exerted by stylus 508 is partially controlled by the degree of pressure exerted by spring 526 against stylus carriage 515, and the pressure may be adjusted by rotationally positioning cap member 513 within ring member threads 512. Limited vertical movement of stylus carriage assembly 479 is permitted because of the slidable engagement of carriage 515 within housing sleeve member 509, and because spline pin 523 is slidable, relative to the carriage, within the slot extending longitudinally of stylus carriage 515.

The outer circumferential surface of ring member 511 defines sprocket 530 for receiving D-axis timing or drive belt 531. Referring to Fig. 21, D-axis drive belt 531 also engages drive pulley 532 which is affixed to the shaft of D-axis servomotor 533, shown more clearly in Fig. 7 and 10. Referring also to Figure 9, D-axis servomotor 533 is affixed to mounting plate 534 bolted to left and right mounting blocks 535, 536 which are affixed and extend downwardly from carriage 505. A mounting plate 540 is similarly affixed to carriage 505 for supporting a D-axis position resolver 541 driven proportionally to the rotation of D-axis motor 533 and D-axis pulley sprocket 530 by means of timing belt 542 engaged with pulleys 543, 544 affixed to the shafts of D-axis motor 533 and D-axis position resolver 541, respectively. The rotation of D-axis servomotor 533 is thus effective to rotatably position the stylus carriage assembly 479 (Fig. 7) about D-axis 181, and accordingly, to position the D-axis cutting angle of stylus 508. Position of stylus 508 is sensed by 9 control computer, (Fig. 15), be means of the signals fed from D-axis position resolver 541, as will be more fully described hereinbelow.

Referring now to Figure 13, translation of stylus housing assembly 479 along the W-axis is accomplished by W-axis motor 545 mounted on the left cutter assembly mounting plate 469 above carriage 505, W-axis motor 545 having a motor pulley 546, engaging timing belt 547 (Fig. 7) which extends from the W-axis motor alongside mounting plate 469 to engage corresponding W-axis drive pulley 550 (Fig. 14), which is non-rotatably mounted on W-axis drive shaft 551. As seen more clearly in Fig. 9, first and second bearing structures 552, 553 are seated within cutter assembly mounting plates 470, 469, respectively, for rotatably receiving W-axis drive shaft 551. W-axis drive shaft 551 includes a threaded mid-portion which extends laterally through bore 552 extending through a mid-portion of cutter assembly carriage 505, the threaded shaft additionally extending through an internally threaded ball nut assembly 553 affixed to the side of carriage 505 within a cutout portion of carriage 505. Rotation of W-axis drive shaft 551 within internally threaded nut assembly 553 effects lateral movement or movement in the W-axis, of carriage 505 and stylus assembly 479 and, as will be seen below, effects cutting of fibrous tape 19. W-axis position resolver 555, as seen more clearly in Fig. 14, includes timing pulley 556 engaging timing belt 560 which extends downwardly to engage W-axis timing pulley 561 (Fig. 9) mounted on a portion of the W-axis drive shaft 551 extending beyond right cutter assembly mounting plate 470.

The cutting mechanism is normally operated while tape 110 is being applied to the mold surface, i.e., when the tape head is moving. This unique on-the-fly cutting capability increases the productivity of the machine.

As a first step in operating the machine, stylus 508 (Fig. 8) is mounted within stylus carriage 515, and the projection of the cutting edge from stylus carriage 515 is adjusted. Preferably the projection of the stylus tip beyond carriage 515 by a distance approximately equal to the thickness of fibrous strip 19. In our experiments it has been found advantageous to subsequently adjust stylus 508 manually and to precisely position the blade for cutting the particular tape employed.

In bench testing, the carriage is drawn laterally across a strip of tape 110 to be used, and adjustments are made to correct scribing of backing tape strip 112, which result from excess projection of stylus 508, or in unsatisfactorily

cutting of fibers 19 which results from insufficient projection of stylus 508. Stylus carriage 515 (Fig. 8) is then mounted within stylus assembly carriage 515 and set screw 523 is tightened. Stylus carriage 515 is then mounted within carriage assembly 479, and cap member 513 is tightened within threads 512 to exert pressure against stylus carraige 515. Testing then continues, with respect to the adjustment of the stylus cutting pressure, by cutting strips of tape 110 in actual operation of the machine and subsequently adjusting the pressure on stylus 508 by means of marginal rotation of cap member 513 within threads 512 until cutting of only fibrous tape 19 is consistently obtained without damage to backing strip 112. The rotational position of cap member 513 may conveniently be marked by indicator means on cap member 513 and ring member 511.

In mounting composite tape 110 on the machine, a roll of tape 110 is placed on supply reel 414, as shown in Figure 5, and a leading strip is drawn from the roll of tape 110 along guide chute 467, between stylus assembly 479 and anvil 478, and subsequently drawn under applicator shoe 462, whereupon backing strip 112 is separated from composite tape 19 and drawn around the takeup reel and adhered by adhesive means to takeup reel 415 for recovering backing strip 112. At this point, torque motors 453 and 457 (Figure 4), driving supply reel 414 and takeup reel 415, are actuated to effect counteracting or counterbalancing torques on takeup reel 415 and supply reel 414 for applying tension to tape structure 110, and the section of backing strip 112 extending behind applicator shoe 462. Preferably, these counterbalancing forces are substantially equal, whereby tape 110 remains stationary absent any external force tending to displace it. Sufficient torque is applied to tension and maintain tape structure 110 and backing strip 112 taut between takeup reel 415, shoe 462, and supply reel 414.

The position of the elements movable about the various axes, i.e. the X-axis, the Y-axis, the C-axis, the D-axis, and the W-axis, is next calibrated with respect to the controls on Allen Bradley machine 278 (Figure 1). This is accomplished by moving tape head assembly 413 and cutter assembly components 474 to known positions, i.e., known, "home" positions, and calibrating the control system of Allen Bradley machine 278 by the adjustment of controls when the controlled mechanisms are in their home position. As an example of the procedure for calibrating the position resolvers relative to the control system, a W-axis limit switch is positioned to one side of carriage 505 (Figure 9), the W-axis limit switch being a normally open microswitch which, upon carriage member 505 contacting the limit switch, transmits a signal indicating that the W-axis home position is immediately outside the edge of the tape. The microswitch is positioned to provide a corse indication to the control system of that position. Subsequently, a fine adjustment of W-axis resolver 555 (Figure 14) may be accomplished by manually rotating the resolver after loosening set screws within its mounting pulley to precisely zero the W-axis control at the edge of the tape. This position indication is entered into the computer as will be described in more detail in the description below of the control system, for effecting a command instruction at an appropriate time to activate the actuator 498 (Figure 8) to urge anvil 478 downwardly against cutting stylus 508 when it is desired to initiate cutting of fibrous tape 19. Pressure exerted against anvil 478 by cam member 501 urges anvil 478 downwardly against the pressure of springs 493, 494 and into contact with the upwardly facing walls of slots 486, 487, through which spring assemblies 493, 494 are extended, whereby anvil 478 is brought into a known position relative to carriage 505 and stylus assembly 479. Activation of the W-axis drive motor is then effected, by rotation of W-axis drive motor 545 (Figure 13) causing rotation of pulley member 550 and W-axis threaded shaft 551 within the threaded circulating ball bearing assembly 553, driving stylus assembly 479 laterally across tape 110. The velocity of the W-axis movement has been found to be uncritical with respect to cutting efficiency, and speeds up to a 1800 inches per minute across the tape have been implemented with no deleterious effects.

Application of fibrous tape 19 to mold surface 412 is accomplished by actuation of the X and Y-axis servomotors, and position feedback systems to cause the tape head assembly to translate across mold surface 412 along a desired X-Y path, while positioning the tape head assembly vertically, by the Z-axis servomotor and a Z-axis servocontrol feedback system and radially, by the R-axis servomotor and R-axis servocontrol feedback system, such that fibrous tape 19 extending beneath applicator shoe 462 is urged by a substantially constant pressure as defined by the setting of counterbalance cylinders 447, 448 against mold surface 412. The weight of tape head assembly 413 is not totally exerted against tape 110, but is reduced by the counterbalancing force exerted by pneumatic counterbalancing actuators 447, 448 (Fig. 6). Movement of the head assembly in the X-Y plane while tape 110 is urged against stationary mold surface 412 induces a linear force to tape structure 110 tending to overcome the reverse torque exerted by supply reel torque motor 453 and withdraw the tape structure from the supply reel 414; and take-up reel 415 is then driven by take-up reel servomotor 457 to take in backing strip 412. Under the control of the control system, tape head assembly 413 is caused to traverse the mold along X-Y vector axes which are mutually parallel and mutually spaced, by a distance equal to the width of the particular tape employed. The tape is cut along a vector line appropriate for terminating tape strip 110 on the mold, continuous with the edge of the workpiece which is being formed. This is accomplished by the control system, as will be

described below. Subsequent to each pass over the mold surface, the tape head may be rotated about C-axis by 180 degrees, and tape head assembly 413 is brought back across the mold along a parallel path spaced alongside the last strip of fibrous tape 19 adhered to mold 412.

It should be noted that when it is desired to cut the tape perpendicularly, movement of the gantry in the X-Y plane is stopped when a position of tape head 413 is reached which is spaced by a predetermined distance from the edge of the mold of the composite structure to be manufactured. With the Y-axis gantry motor and the X-axis gantry motor deactivated, the head is stationary, and the W-axis motor is energized to cut tape 110 perpendicularly, or normal to its longitudinal axis. However as previously mentioned tape cutting can be accomplished on-the-fly if it is acceptable to cut at an angle.

The tape laying operation is controlled by a computerized numeral control system utilizing numerical control system 600. Control system 600, as shown diagrammatically in Fig. 15, preferably has a programmable controller interface 601, as an integral part of the computer, which receives signals from several of the position limit switches and transducers, as will be described. The programmable controller interface 601 takes the place of an equivalent, electromechanical relay or timer counter system utilizing logic sensing and generation functions. The use of the programmable controller interface 601 and its associated software program is preferred for its programming flexibility and its elimination of maintenance and reliability problems associated with electromechanical relay logic systems.

An example of such an internally programmed machine is that manufactured by Allen Bradley Corporation as model No. 7320, having a major axis, input/output control module 602 with sufficient output channels for position command control of the major axes positioning servomotors (i.e., X, Y, C, D and W-axis servomotors 280, 284, 36, 533, 545) and sufficient input channels for their corresponding position transducer feedback units, i.e., the X, Y, C, D, and W-axis position resolvers 281, 285, 40, 541, 555. These positioning motors are controlled by control system 600, as to their position and velocity, according to the position execution sequence program (commonly termed in the art the "part program") which is supplied suitably on 8-hole punch tape entered into computer processor unit 603 from a tape reader, for the individual workpiece configuration required. Alternatively, position control commands can be entered by means of the integral keyboard on the Allen Bradley numerical control system to override part or all of the part program or, if additional memory storage is required, a back-up unit such as an Apple II computer system, can be integrated with the Allen Bradley keyboard to provide additional memory capacity.

Auxiliary input/output control modules 604 are provided for monitoring additional, digital auxiliary position sensing devices and for controlling Z and R axis servomotors during the initial positioning of the tape applicator head 413 into contact with mold surface 412, and the power input to the take-up and feed reel servomotors 457 and 453, respectively, for example. Such position control functions do not need to be continuously controlled by the internal computer process or circuit 603, but instead may be more easily and economically controlled by adaptive feedback systems such as indicated by the external adaptive control circuitry 605 (Figures 15, 16 and 17) when control system 600 is in the adaptive control mode. These adaptive feedback system, to be described below, are designed to automatically control the Z and R axis movement, as will be described, independant of control from control system 600. Other inputs to control system 600 may include, for example, signals received from position or limit switches sensing "over travel" and/or "home" position of components in the W-axis, Z-axis, C-axis, R-axis, X-axis, and Y-axis, as desired.

Continuous, major axis control is performed according to a resident program in processor section 603 in the computer memory, in cooperation with the position execution sequence command program (part program) entered into the computer memory by means of the integral machine keyboard, or the tape reader, in accordance with programming techniques commonly used in the art. Positioning in the Z-axis and R-axis is also controlled by processor section 603 through auxiliary input/output control modules 604 but only to effect initial or course positioning by Z-axis and R-axis servo motors 50, 72.

With continued reference to Fig. 15, computer control interface circuits 601, and position input and output devices 602 are shown in connection with input devices such as position resolvers for X, Y, C, D, and W axes 281, 285, 40, 541, 555 which position resolvers are in mechanical association with servomotors 280, 284, 36, 533, 545 for these axes. Position indicating switches are suitably normally open position indicating switches as shown by exemplary limit switch 606.

Z and R-axis movement is controlled alternatively by adaptive control system 605 (Figures 15, 16, 17) called the automatic tracking system, during movement of tape head assembly 413 along mold surface 412, and by initial, gross movement control during approach to the mold. The sensors are mounted within applicator head 413 for sensing movement of applicator shoes 465 about the R-axis relative to tape head 413, and a Z-axis sensor mounted on backing plate 432 to sense the relative position of actuator rod 447a, is adapted to provide input signals relative to movement in the Z-axis of shoe 465 and supporting the framework relative to tape head framework 413. The auto tracking inputs to control system 600 are analog signals which are

received within adaptive control circuit 605, which is an analog/digital control circuit for receiving input signals indicative of position information, i.e., Z and R-axis position, for adaptive normalization of Z and R-axis position relative to a plane normal to the mold surface, when Z and R-axis control is in the adaptive operational mode. Alternatively, circuit 605 receives initial or course Z and R position commands through control console 604. Feed reel 414 and take-up reel 415 enable/disable commands are originated in console 604, as a result of command signals from computer processor 603 as defined by the resident, auxiliary function control program. Analog output signals of a suitable voltage level and polarity are conducted from adaptive control circuit 605 to the respective servomotor controllers, comprising, for example, dc amplifiers 610, 611, for feed reel and take-up reel motors 453 and 457, respectively. Similarly, analog output signals of appropriate polarity and magnitude are provided to Z and R axis motor controllers for Z and R-axis servomotors 50, 72. Input/output module 602 has its outputs connected to provide analog signals of appropriate magnitude and polarity to DC amplifying motor controllers for powering servomotors for X, X', Y, C, D, and W axes 290, 291, 292, 293, 294, 295.

As was discussed summarily in the earlier section relating to initial activation of the apparatus, during the initial execution of a normal control command sequence, the tape laying head and associated components are positioned in the X, Y, C, D, and W home positions to provide an initial reference calibration within computer memory 615, from which all subsequent commands will be referenced. At this time, a preselected position execution sequence command or part program is executed. The following is an exemplary part program, suitably utilized to form a workpiece of rectangular configuration with tape strips laid along a 45° path from the X-axis. This example is of a typical part program, and the steps required to lay one strip of composite tape at a 45 degree vector angle from X axis, and to shear the end of the strip at a 45 degree angle.

The first sequence command instructs the machine to position tape head assembly 413 over mold 412 in order to lay the initial strip of composite tape 110.

N1 FO X146.54 Y85.336 WO C315 D135.

N1	Program execution sequence number
FO	All axes velocity to execute at rapid traverse (1200"/min for the X, Y, and W axis, 3600 degrees/min for C axis and D axis positioning)
X146.54	X Axis to 146.540 inches from home
Y85.336	Y Axis to 85.336 inches from home
WO	W Axis to 0.000 (home position)
C315	C Axis to +315.000 degrees from home
D135	D Axis to +135.00 degrees from home

N2 MO4 — lower the Z axis to the mold surface 412 and inhibit further sequence execution until Z axis is in contact with the plane (i.e. the mold surface 412) and has assumed adaptive control status with R axis.

N3 F600 X149.798 Y88.489 — position x and Y axis along a 45 degree vector for a linear distance of 4.606" at a velocity of 600 inches/min. (The 4.606 inches is the "lead in" distance, at the end of which the command sequence for shearing the tape 110 will be performed.)

N4 F450 W3.2 X152..06 Y90,751 MO7 — Extend anvil and shear tape at a 45-degree angle for 3.2" at a velocity of 450"/min.

N5 MO6 — Retract anvil.

N6 F600 X158 Y96.796 MO3 — complete rollout dimension and execute MO3 (raise Z-axis approx. 3" via timer in CNC).

N7 FO X158 Y101.081 C135 WO D45 — index Y, C, D and W axis positions at rapid traverse and prepared to lay the next adjacent strip of tape.

N8 (etc. — continue laying subsequent strips of tape as shown above).

Step N2 accomplishes actuation of the adaptive control system for Z and R axes.

Step N3 is the lead command instructing tape head 413 to travel in the X-Y axis for the distance required to lay the initial length of tape 110 to a position at which the tape cutting sequence must be initiated. A lead length of, for example, 10.1 inches, is required for accommodating the distance between applicator shoe 462 and the cutter assembly 474.

Step N4 is the actual cutting sequence command, in which X-Y axis velocity is reduced, but not terminated, as the tape is cut by movement of stylus 508 along the W-axis.

Referring again to Figure 15, after circuit 605 receives the initial or course Z and R-axis position commands through control console 604, the Z and R-axis automatic tracking sensors need to be positioned in the Z and R-axis "home" positive to provide an initial reference point. The procedure for establishing these reference points must be followed to begin each new or different mold 412 and is relatively easy to follow and complete. The Z-axis servomotor is actuated to bring the tape laying head 413 into contact with mold 412. The position sensor is then calibrated or zeroed to correspond to the exact point of contact between applicator shoe 465 and mold surface 412. At this calibration position the weight of the applicator head is exactly counterbalanced by

counter balance cylinders 447 and 448. The tape would then be applied with no pressure behind it. In this position the tape applicator head could also be adapted for use in testing and inspecting a contoured surface. Alternatively the counter balance of cylinders 447, 448 are adjusted to allow a pre-selected pressure to be applied to the tape as it is being applied to mold 412 corresponding to the weight of applicator head 413, that is not then counterbalanced. At this pre-selected pressure the Z-axis automatic tracking sensor or sensors is calibrated to zero.

To set the R-axis sensor it is preferable to provide an adjustment that corresponds to the same exact positive as that to which the Z-axis sensor was set. To do this the R-axis sensors are calibrated or zeroed when tape head 413 pivots about the point of contact between shoe 465 and the mold surface.

Once the Z and R-axis sensors are calibrated the tape applicator bead 413 is ready to begin operating. As head 413 is moved across the contour of mold surface 412, X, Y, C, D and W axis servomotors 280, 284, 36, 533, 545 are controlled by the program in Allen-Bradly computer. Z and R-axis servomotors 50 and 72 are controlled independently by the adaptive automatic tracking sensors. The sensors identify changes in the contour of the mold as denoted by the shifting position of tape applicator shoes 465 relative to the home or zeroed position and signal the appropriate servomotor reaction to bring the shoe back to the zeroed a home position. A variety of sensors can be employed in the automatic tracking system. For example direct switching, such as limit switches, can be used to signal the change of position of head 465, air pressure differential sensors can be used to denote the position change or the preferred system employs a series of potentiometers such as Baurns 2.25 inch stroke, 10K ohm linear positive-transducers, catalog No. 80294-2001085016. The Z-axis in this embodiment employs only one transducer should be selected to accommodate the maximum vertical change of mold surface 412 be traversed. For example the Bourns transducer specified could accommodate a maximum change in each direction of 1 1/8 inches if the zero point selected carefully, or a total change of 2 1/4 inches. Once calibrated or zeroed the transducer will track the use and full of applicator head 413 as it works against the counterbalance cylinder. Similarly, the R-axis in this embodiment employs two sensors mounted on either side of applicator shoes 465 as shown in Figure 4.

Z-axis sensor 401 is fixedly mounted to backing plate 432 and has movable sensor shaft 402 which extends downwardly toward the flange member 403, that anchors activator rod 447A of pneumatic counterbalancing cylinder 447 (Fig. 27). An external spring keeps the sensor shaft 402 in contact with flange 403, whereby movement of shoe assembly 462 and the associated components, especially shoe 465, relative to the backing plate 432 causes movement of sensor shaft 402 as tape head 413 and shoe 465 are brought downwardly into contact with mold 412. Referring to Fig. 15, Z axis sensor 401 comprises a translatory potentiometer, operable to generate an analog voltage signal, at its wiper element, which is proportional to the vertical displacement of sensor shaft 402 is response to vertical movement of the movable tape head elements, e.g. left vertical support plate 421, mounting plate structure 416, right vertical support plate 472, when tape head 413 is in contact with mold surface 412. Referring to Fig. 16, the Z-axis sensor 401 is shown schematically as having positive and negative, 5-volt potential sources connected to either side of the potentiometer resistive element. The output of the movable (wiper) element is connected through lead 700 to the non-inverting input of a BI-FET operational amplifier 701 having high impedance inputs, which is herein employed as a unity gain current amplifier. Capacitor 702 is connected in series between lead 700 and ground for filtering voltage transients and electrical noise from lead 700.

The outputs of unity gain current amplifier 701 are fed through lead 704 to the inverting input of Bi-FET operational amplifier 705, employed as a differential voltage amplifier for providing a voltage output proportional to voltage outputs derived from Z-axis potentiometer sensor 401. The non-inverting input of Bi-FET amplifier 705 is connected to an adjustable source of potential 707, comprising a potentiometer having its resistive element connected between positive and negative potential sources whereby an operator, by adjusting potentiometer 707, may adjust the potential applied to the non-inverting input of operational amplifier 705. This adjustment allows the operator to adjust the DC offset output from amplifier 705 to correspond to the adaptive tracking system contact point of shoe 465 on mold 413.

Output voltages from operational amplifier 705 are thus adjustable to be proportional to the successive positional translations of the movable portions of tape head 413. The outputs, are fed through potentiometer 703 and lead 706 and to an analog switching device 713. Switching device 713 is a solid state, analog switching device equivalent to a single pole, single throw switch. The output of analog switch 713 is fed through lead 708 to driver lead 709 which is ultimately fed through operational amplifier 710, which is also configured as a unity gain operational amplifier, then to output 711 which is connected drivingly to the Z axis power amplifier, or motor controller 712 (Fig. 15), for driving Z axis servomotor 50. Referring to Fig. 15, lead 711 is shown as connected between adaptive control circuit 605 and the Z axis power controller 712, which, in turn, powers Z axis servomotor 50.

Manually adjusted potentiometer 703, connected in series between lead 706 and the output from operational amplifier 705, permits

adjustment of the output level from amplifier 705 and thereby serves to attenuate the voltage signals received from amplifier 705 to attenuate, if desired, the response of Z-axis servomotor 50 to these signals derived from amplifier 705. Potentiometer 703 permits "fine tuning" of the response in, during the automated contour following operation to variances in the contour of mold surface 412, thereby preventing lag in position response, or conversely, overcompensation to variances in mold surface 412.

Having now described the primary Z-axis adaptive control channel, reference is again made to Fig. 16. Another reference voltage potentiometer 720, similar to the reference voltage potentiometer 707, is provided for establishing an adjustable reference voltage to the inverting input of voltage comparator 721. This allows the operator to adjust the reference voltage, as detected by voltage comparator 721, to correspond to the point in which the Z-axis assumes adaptive tracking once shoe 465 has intercepted mold 413. The non-inverting input of comparator 721 is connected sequentially through lead 722 and lead 704, for receiving the voltage level (indicative of Z axis position) received from the unity output current amplifier 701. The output of comparator circuit 721 is a digital signal indicative of contact with the plane of mold 412 by the applicator shoe 465. Filtering capacitor 723 is connected between the output of potentiometer 720 and analog voltage comparator 721. The output of the analog voltage comparator 721 is conducted through lead 725, and a hysteresis feedback circuit. The hysteresis circuit comprises resistor 730 connected in series between the non-inverting input and the output of voltage comparator 721, and further includes resistor 731 connected in series between the non-inverting input of voltage comparator 721 and lead 722, to thereby provide a 1-to-10 ratio of feedback hysteresis or negative feedback across voltage comparator 721, prevent any substantial oscillation in the signal output. Without the hysteresis feedback circuitry, the output voltage from comparator 721 would tend to oscillate when its input voltages approached or dwelled at the equality threshold switching point. The hysteresis circuit, as will be understood by those in the art, adds or subtracts voltage to the non-inverting input of comparator 721 to prevent oscillatory switching and to prevent switching until the magnitude of the voltage applied to the non-inverting input is significantly greater than the threshold reference voltage, 10-to-1 ratio has been found to be effective in the present circuit, in that a high level of hysteresis is preferred.

Potentiometer 720 is adjustable by an operator to permit adjustment of the degree of depression of the plunger of potentiometer 401 needed for generating the digital output signal, along lead 725, indicative of an "on-plane" condition. Output lead 725 is connected through Invertor 735 to NOR gate 732, employed as a NAND gate, whose other input is derived through lead 733 from a manual control circuit section 734, to be described. The output from voltage comparator circuit 721 is inverted, by inverter 735 connected in series with NOR gate 732, whereby a negative or "logic zero" signal applied through NOR gate 732 normally enables analog switch 713, permitting the Z axis differential signal derived from lead 706 to be transmitted, through leads 708, 709, and buffer 710, to Z axis power controller 712 (Fig. 15) and servomotor 50 (Fig. 15).

A transistor control circuit section 740 (Fig. 16) is also connected, through lead 726, to the output of voltage comparator 721, circuit 740 serving to generate a digital output signal for CNC computer 603 indicative that contact with the plane of the mold has been made. Lead 726 is connected to the base of an NPN transistor 741 whose emitter is connected to ground and whose collector is connected to one side of a relay 742 whose other side is connected to 24-volt power source 743. When transistor 741 is turned ON by the signal from comparator 721, relay 742 is energized causing, the contacts of relay 742 to close for bringing 24-volt potential to output terminal 744. Output terminal 744 from the relay is, for convenience, fed through the Input/output terminal rack 604 (Fig. 15), from which the inputs to processor computer 603 are derived. Control circuit section 740 thus serves to transmit to computer 603 an "on-plane" signal, to inform the computer that the adaptive control of Z-axis positioning is now in effect.

The output derived from autotracking sensor potentiometer 401 is fed through the autotracking sensing circuit 605, Fig. 15, which includes generally operational amplifier 705, analog voltage comparator 707, and associated circuitry (Fig. 16) as previously described, for automatically following the contour of mold 412 as tape head 413 traverses mold 412 as tape 110 is being laid. Alternatively, CNC control (derived from the part program) or manual control of the Z-axis position, is derived through processor computer 603, via input/output rack 604, for permitting initial or gross Z axis control and for permitting manual override of the automatic contour following or "autotracking" under certain conditions, to be described. The autotracking input (derived from potentiometer 401) for Z-axis control may only be overriden by a CNC control for a "Z raise" command. This of course is for safety reasons, to prevent downward movement of tape head 413 which could possibly damage portions of tape head 413.

CNC computer 603 is connected to first and second, Z-axis RAISE and Z-axis LOWER, command input terminals 750, 751 (Fig. 16), which are connected to respective relays 752, 753, the relays having double-pole, double-throw contact configurations. The contacts illustrated in the drawing as the "upper" contacts of switching elements 754, 755 of the relays 752, 753, respectively, are connected through leads 756,

757, respectively, to the inverting and non-inverting inputs, respectively, of differential operational amplifier 760, whose purpose is to generate a command signal of a given polarity and magnitude, for ultimately driving Z-axis servomotor 50. An analog ramp voltage generator 763 (and a similar ramp generator circuit 764 connected to the second relay contacts 757) is provided for modifying the signals to be fed to servomotor 50, for smoothing the response. Considering circuit 761, and assuming contacts 754 are normally open, capacitor 763 is normally discharged, in that it is discharged through lead 765, through contacts 754, through lead 766, through resistor 767, to ground. Upon energization of relay 752, capacitor 763 is charged by current conducted through contacts 754 which connect through lead 768 and through resistor 769 to a 5-volt positive potential source 770. Thus, the potential upon lead 763 begins to rise upon energization of relay 752 with an RC time constant that is dependent upon the values of capacitor 763 and resistor 769, resulting in an increasing potential at the inverting input of differential operational amplifier 760. This produces a negative voltage from the output of differential operational amplifier 760, which is proportional to the positive signal received through lead 756, for actuating with an initially increasing power level Z-axis servomotor 50 to thereby raise tape applicator head 413. If resistors 767 and 769 are of equal values, as in the present circuit, upon subsequent reversal of the position of relay contact 754 the output voltage at lead 756 will diminish at the same rate at which it rose upon the initial closure of contact 754, bringing the Z-axis motor 50 to a stop over a desired period of time. The output received from the similar, second switching circuit 762 operates in conjunction with signals derived through contacts 755 to produce similar control signals to the differential operational amplifier 760 which, because they are applied to the non-inverting input, produce output signals of an opposite polarity, and thus will drive Z-axis servomotor 50 in an opposite direction to lower tape head 413.

First and second amplifier gain feedback circuits 771, 772, mutually connected in parallel, are connected in series across the differential operational amplifier 760 for providing additional, independent control of the gain of differential operational amplifier 760 with respect to positive and negative signals, i.e. LOWER and RAISE command signals. Circuit 772, for example, attenuates the gain applied during RAISE commands (i.e., with negative potential) as enabled by diode 776, which is forward biased to permit conduction of current through feedback circuit 772 when the output from the differential operational amplifier 760 is negative. Potentiometer 775 is connected in series with diode 776 in circuit 772 for controlling the feedback, and thus, amplifier gain. Diode 773 in feedback circuit 771 is connected in inverse polarity relative to diode 776, for preventing current flow through feedback loop 771 when a negative potential is received through the output of differential operational amplifier 760. During LOWER commands, the reverse applies. Diode 776 prevents current flow through feedback loop 772, and amplification is controlled by feedback circuit 771 by adjustment of the corresponding potentiometer 774. A further potentiometer 777 is connected between the output of the operational amplifier 760 and ground, for permitting operator control or fine tuning of the output signal to be applied through second analog gate 781, to be described, and through leads 709, and 711 to Z-axis servocontrol motor 50 to permit attenuation of the servomotor response as desired.

A logic circuit generally indicated at 780, comprising a plurality of gates and switches now to be described, provides the ability to selectively enable or disable manual and CNC part program control signals. A second function of logic circuit 780 is to form a digital safety interlock circuit, preventing downward, operator controlled movement of tape head 413 past a safe position relative to the mold surface 412, i.e., preventing downward movement of the tape head 413 which could damage tape head 413.

Second analog gate 781 is connected in series between lead 709 and the output of potentiometer 777. Analog gates 781 and 713 receive bias voltages, from a plus and minus potential source 782 and 782B, respectively, and may receive an enable voltage through lead 783 from NOR gate 784 (which is configured as a NAND gate). Analog gate 781 is conductive, when enabled by gate 784, to provide manual RAISE and LOWER command signals through lead 709. Analog gate 781 is inhibited when no enabling signal is received from NAND gate 784, to interrupt CNC commands received through differential amplifier 760 and to permit automatic, adaptive Z-axis control, through control signals derived through lead 708 from amplifier 705. NAND gate 784 includes a first input connected through lead 785 and a second input connected through lead 786, and analog gate 781, it is enabled when both inputs of NAND gate 784, i.e., the inputs from both leads 785 and 786, are of zero potential. The circuitry connected to the lower set of relay contacts (787, 788) of relays 750, 751, respectively, is operable in connection with logic circuitry 780. Lead 785, connected to one input of NAND gate 784, is connected to the output of NOR gate 790 which has first input 791 connected to the common (switching element) terminal of contacts 788, which, in the deactivated condition shown in the drawing, is connected to ground through leads 792 and 794. The opposite input of NOR gate 790, connected through lead 793, is similarly connected through contacts 787, through lead 794, to ground. Thus, in the condition shown, the inputs to NOR gate 790 are identical (at ground level) and the output fed from NOR gate 790 through lead 785 is a positive 5 volts (derived from a voltage source,

not shown, connected across NOR gate 790 and also across NAND gate 784). The 5-volt potential applied through lead 785 enables NAND gate 784, which causes it to produce a zero potential output at its lead 783 to analog gate 781. This interrupts the circuit between the differential operational amplifier 760 and lead 709, preventing Z-axis actuation through amplifier 760. The condition of contacts 787, 788 illustrated in the drawing applies to the condition when no Z-axis command signals are derived through Z-axis command input terminals 750, 751 in response either to manual Z-axis control or "part program" Z-axis control through the CNC computer 603. CNC Z-axis RAISE and LOWER command signals are exclusive, i.e., a safety interlock circuit within computer 603 is provided for preventing simultaneous activation of two relays 752, 753.

Assuming now that a CNC LOWER signal is received as a voltage potential applied at terminal 751, relay 753 is activated and contacts 755 are closed, generating an analog LOWER signal through differential operational amplifier 760 as previously described. In addition, relay contacts 788 is closed, providing positive 5-volt potential from source 770 through lead 795, through lead 791, to NOR gate 790. The potential derived from lead 793 to NOR gate 790 remains at ground and accordingly, the output of NOR gate 790 goes to zero potential, which disables NAND gate 784, which in turn enables the analog gate 781 to conduct a manual CNC command signal through output terminal 711, driving the Z-axis servomotor in the down direction. This operation may also be affected by further circuit elements activated upon contact with mold surface 412 (i.e., AND gate 796 and inverter 797, to be described).

In a similar manner, NOR gate 790 is enabled to disable NAND gate 784, to then enable analog gate 781, when a signal is received through input terminal 750 to drive tape head 413 upwardly. In this event, contacts 787 will be reversed from the position shown in the drawing, permitting positive potential from source 770 to travel through lead 793 to NOR gate 790. Positive potential from lead 793 enables NOR gate 790 to disable NAND gate 784, and to thereby enable analog gate 781. In response to a CNC generated UP command received at terminal 750, a positive 5-volt potential is applied through lead 793 and subsequently through lead 798, and thereby a positive 5-volt potential is supplied to the input of inverter 797. Lead 798 is also connected through lead 733 to the second input terminal of NOR gate 732. Positive potential applied through lead 733 to NAND gate 732 which enables gate 732, which disables analog gate 713, which prevents the application of the adaptive (autotracking) control signals through lead 708 to the Z axis control circuits 711. Thus, during an RAISE command under any circumstance, autotracking will be disabled. The 5-volt potential from lead 798 is also applied to inverter 797, where it is inverted, and the resulting signal disables AND gate 796, which disables NAND gate 783 (providing that no enabling voltage is supplied through lead 785) which in turn enables analog gate 781, permitting Z axis energization through differential amplifier 760.

Summarizing the operation of the circuitry above, lead 785 to NAND gate 784 provides a command input for entering RAISE or LOWER commands derived from the relays 752, 753 and from the CNC inputs 750, 751. The lack of a command signal on lead 785 disables NAND gate 784 which in turn enables analog gate 781 for permitting CNC control, provided that there is no disabling signal received through lead 786. The purpose of AND gate 796 is to provide a disabling signal to NAND gate 783 as a result of a default between the inputs of gate 796 as a result of either (1) a Z-axis-on-the-plane signal being received through lead 799 or, (2) a zero voltage being received through inverter 797 as result of an RAISE command. The "on-the-plane" signal received through lead 799 is also transmitted through lead 800, at its opposite extension, to the R-axis control circuitry now to be described.

The output received through lead 799 is conducted through connecting lead 800 to the R-axis circuit as illustrated in Figure 17. The output through lead 799 is a positive 5-volt signal generated when an "on the plane" is generated by the voltage comparator 721 (Fig. 16) upon contact with the mold surface plane has occurred results in the generation of an "on-the-plane" signal. The on-the-plane signal is received in two sections of the R-axis control circuit as illustrated in Figure 17. With primary reference to Figure 17, a Z-axis "on-the-plane" signal is conducted through lead 800 to a first, analog gate 801 to enable analog gate 801. As will be more fully understood from the description to follow, gate 801 then permits an automatic R-axis control signal to be transmitted through lead 802 to a unity gain current amplifier or buffer circuit 803 which is connected through lead 804, as seen also in Figure 15, to the R axis power amplifier 805 driving R axis servomotor 72 (Fig. 15), to position the tape head 413 about the R-axis. As will also be more fully understood from the following description, the "on-the-plane" signal received through lead 800 also shown in the drawing as connected to one of the inputs of second NAND gate 810) serves to enable NAND gate 810, which disables a second analog gate 811, inhibiting manual or CNC computer control signals which would be transmitted through output lead 812 to unity gain current amplifier 803.

Automated or adaptive R-axis control is derived from first and second R-axis sensors 813, 814 which are positioned on the right and left sides of the tape head shoe 465 as shown in Figure 4. Referring to Figure 4, sensors 813, 814 are installed on the support frame 416 of shoe 462 and have spring-loaded plungers which are maintained in contact with flanges 815, 816

mounted on the right and left sides of the shoe element structure. Sensors 813, 814 are also shown in Fig. 15. Accordingly, limited rocking movement of shoe 465 about bolt 466 causes differential movement of the plungers of transducers 813, 814, resulting in a position control signal which may be sensed by the circuit now to be described. Referring again to Figure 17, positive and negative 5-volt sources of potential are connected to respective opposite sides of the resistive elements of potentiometers 813, 814 (as in the Z-axis transducer 401, Fig. 16, described above). Output leads 817, 818 are connected from the movable element of potentiometers 813, 814, respectively, to the non-inverting inputs of first and second unity gain, buffer amplifiers 819, 820. Buffer amplifier 819, 820 are provided with feedback loops 821, 822, establishing unity gain (no voltage amplification), and amplifiers 819, 820 thus serve as impedance isolation and current amplifier devices to provide a low impedance input to differential amplifier 823. Differential amplifier 823 has its respective inputs connected, through leads 824, 825 and resistors 826, 827, to the outputs of buffer amplifiers 819, 820, respectively. The output of differential amplifier 823 is proportional in voltage level to the differential potential between the output of the R-axis sensors 823A, 814, and its polarity corresponds to the direction of error (R-axis differential), whereby its output is proportional to the degree of R-axis displacement. In addition, its output is controlled by amplifying gain loop circuit 828 connected in series across its output lead 829 and its inverting input, feedback loop 828 incorporating an adjustable potentiometer 830, which operates in conjunction with fixed resistor 823 to control the voltage gain of differential amplifier 832. Resistor 832, connected between the non-inverting input of differential amplifier 823 and ground, in combination with resistor 827, resistors 826 and 831 and variable resistor 830, determine the overall gain of differential amplifier 823. Operator controlled potentiometer 833 is then connected series between output lead 829, lead 828, and analog gate 801 for providing adjustable attenuation of the output derived from differential amplifier 823, whereby the response of the R axis servocontrol system to a given differential R axis input can be attenuated if desired by an operator. In essence, this adjustment slows somewhat the R axis response to given inputs.

The output received from the potentiometer 833 is passed through the analog gate circuit 801, when that circuit is enabled by the "on-the-plane" signal derived from lead 800, and an output is subsequently passed through lead 802 to the unity gain current amplifier 803 and output lead 804 to activate R-axis servosystem 804, 805, 806 (Figure 15). The command signal transmitted through leads 802, 812 through current amplifier 803 is proportional in degree to the differential signal derived from right and left sensors 813, 814 and corresponds in polarity to the relative difference in potential of two sensors 813, 814, determined by the relative directions of displacement of their respective sensing elements. The R-axis autotracking control circuit as described thus serves continuously to correct disparities between the R-axis angle of the tape applicator head 413 and the surface of the local area of the mold as tape head 413 passes over varying contoured positions of mold 412. This is an important, advantageous feature of the invention in that automatic, or adaptive tracking of the contour of the mold 412 is accomplished independently of the computer controlled (CNC) commands derived from the part program, i.e., the programmed "X", "Y", "C", "D", and "W-axis" commands. This greatly simplifies the programming of the machine, lessens the complexity of the computer controlled circuitry and the computer program, and enhances the flexibility of the machine. Operator controls are provided to adjust the actual response of the machine to given dynamic parameters. Without the adaptive control circuitry, a detailed list of cartesian coordinates would have to be plotted for each individual mold, and a complex computer program set up to accommodate or follow the particular three dimensional contours of mold 412 by continuously solving multiple cartesian coordinate equations. Because of the complexity of such calculations and apparatus, existing state-of-the-art tape laying apparatus have not incorporated means for tracking variable or elevational contour variances, i.e., three dimensionally contoured mold surfaces.

In addition to the adaptive R axis controls derived from the signals generated through analog gate 801 conducted through lead 802, R-axis control is also accomplished through the CNC machine under operator control or through the part program, by a second input circuit indicated generally at 840. First and second control signal input terminals 841, 842, (connected through outputs from the input/output circuitry rack 604 Fig. 15), are connected to the nongrounded sides of first and second relays 843, 844 which incorporate single relay contact sets 845, 846 respectively. Input 842 receives commands for effecting an R-axis LEFT movement, and input 841 receives R-axis RIGHT command signals. Considering the operation of relay 843, assume that a command signal is received through input 841, closing the movable element of contacts 845. A 5-volt potential is thereby applied from source 847, through lead 848 and subsequently through lead 849, to the inverting input of differential amplifier 850. A bridge circuit, comprising bridge resistor 851, is connected in series between the inverting input and the output of differential amplifier 850. Resistor 851 is equal in value to resistor 852 connected in series with lead 849 and the inverting input of the differential amplifier 850, whereby unity gain is effected. Unity gain is also achieved with respect to the non-inverting input, in that resistor 853 is equal in value to resistor 851, and with resistor 854 which

is connected to ground. Ground reference resistor 855, is connected between ground and output lead 849, and ground reference resistor 856 is connected between ground and a corresponding lead 857 connected to the moveable element of switching elements 846, for providing a ground reference voltage during the period in which the movable switching elements of relay contacts 845, 846 are in transient (wherein they are moving or "floating" between the fixed contacts and would otherwise generate undesirable transient voltages to the inputs to differential amplifier 850).

The output of differential amplifier 850 varies in polarity depending upon which of its inputs is activated (i.e., which of relays 843, 844 is energized), and since it is of unity gain, its output will be substantially level. Its output is transmitted through leads 858 and 859 and through potentiometer 860, which may be operator-controlled for attenuating response of the R-axis servocontrol system as desired. Subsequently, the output from differential amplifier 850 is transmitted through lead 861 and to analog gate 811, which, if enabled, transmits the signal through lead 812, and unity gain amplifier 803, to the R-axis servocontrol system.

Analog gate 811 is enabled through a signal derived from lead 870 connected to the output of a NAND gate 810 which has a first input 800 derived from the Z-on-the-plane output voltage comparator 721 (Fig. 16) and a second input connected through lead 871 from NOR gate 872. If no signal is received through either input lead 871 or 800, the output of NAND gate 810 is "logic 1," which enables the analog gate 811. Should there be a 5-volt on-the-plane signal derived from lead 800, however, NAND gate 810 will unconditionally be enabled, producing a "logic zero" (zero voltage) to analog gate 811 which will disable gate 811. This prevents manual or part program R-axis commands from activating the R-axis servosystem when the tape head is "on-the-plane" or in contact with the mold. A "logic zero" output must thus be received from NOR gate 872 as well as from lead 800 to disable NAND gate 810 and enable analog gate 811. Energization of either of relay contacts 843, 844 will enable NOR gate 872, producing a "logic zero" signal through lead 871, and, should there be no on the plane signal derived through lead 800, NAND gate 810 will be disabled, energizing analog gate 811.

Upon rotation of the tape head 413, applicator shoe 465 can be temporarily out of alignment with the surface of mold 412. If the mold plane, at the point where the tape head was lifted, was not perfectly parallel with applicator shoe 465, correction of the R-axis position will be made. An internal program within the computer control (CNC) will execute at this time providing an R-axis drive signal of sufficient duration and direction to "compliment" the former applicator shoe angle of alignment thus providing a near parallel condition between mold 412 and applicator shoe 465 prior to lowering the applicator head back down to the mold surface.

The purpose of the R-axis null circuitry 865 is to inhibit servocontrol movement along the X, Y, C, D, and W axis until R-axis position relative to the plane of the mold has normalized, within selected boundary limits, at which time it is appropriate to continue X and Y axis movement of tape head 413. Absent this delay, tape 110 would initially be applied to mold surface 412 at an angle which would tend to skew the tape laterally, and tape 110 would be applied with substantially uneven pressure laterally across tape shoe 465.

Referring to Fig. 17, a first voltage comparator 876 has its non-inverting input connected through lead 878 to lead 880, which is connected to the output of potentiometer 833. A second voltage comparator 877 is connected in parallel with voltage comparator 876, and has its inverting input terminal connected through lead 879 to common lead 880. The parallel voltage comparator circuits, as well be understood from the following description, serve to generate a reference voltage proportional to the R-axis corrective command signal derived from R-axis sensors 813, 814. The negative input of voltage comparator 876 is connected through lead 881 to a potentiometer 882 connected between a negative 5-volt potential source 875 and ground for providing a reference comparative voltage to the inverting input of voltage comparator 876. A resistor 883 is connected between potentiometer 882 and the negative voltage source 875 forming a voltage divider for adjusting the voltage level. Similarly, a variable potentiometer 886 is connected between ground and a 5 volt source of positive potential 874 through a resistor 873 providing potential, through resistor 888, to the non-inverting input of voltage comparator 877. Adjustment of potentiometers 882, 886 permits adjustment of reference voltages against which the R-axis master error signal derived through lead 880 is compared. The outputs of voltage comparators 876, 877, are connected through common lead 889. First and second voltage comparator resistors 884, 855 are connected in series across the non-inverting input circuits of the voltage comparators 876, 877, respectively, for providing a hysteresis response in conjunction with input resistors 887, 888 respectively, to prevent oscillation of the output of voltage comparators 876, 877 near their threshold voltages. When both of voltage comparators 876, 877 receive potential upon their input lead 878, 879 which are within the preselected null boundaries defined by potentiometers 882, 886, their conductance to ground (as indicated at 891, 892) will be removed, allowing potential on lead 889 to rise. Lead 889 is connected through a resistor 875 to a positive 5-volt potential source 893, and positive potential is then conducted to the base of an NPN transistor 894. Transistor 894 has its emitter connected to ground and its collector connected through lead 895 to NOR gate 896 which is employed as a nand gate.

NAND gate 896 has one input connected through lead 897 to receive an inverted Z-on-plane signal derived from logic inverter 735 (Fig. 16) which provides half of the disabling signal to NOR gate 896. The other half (derived through lead 895) is derived when tape head 413 has come within the null boundaries set by potentiometers 886, 882. When both these input signals are low, the output of NOR gate 896 is enabled and goes "high" or to a "logical one" level, turning on inverting transistor 900, which is turn applies a ground potential through the emitter/collector circuit of transistor 900 closing a circuit to ground from a positive 24-volt source 901, through relay 902, to ground. This actuates the relay 902 to effect closing of its contacts 903, providing a voltage potential from positive 24 volt source 904 through contacts 903 to output terminal 905 which is connected through the input/output rack 604 (Fig. 15) to computer 603 for enabling the computer to follow X, Y, C, D, and W commands derived from the part program.

In summary of the above, circuitry 865 inhibits operational command signals derived from the part program until R axis normalization has occurred, within the boundaries set by potentiometers 886, 882.

A homing corrective circuit 910 is employed for generating an attenuating signal input to lead 802 for decelerating R-axis movement as tape head 413 is approaching a center position, as during initial homing of all axis of the machine. R-axis centered position is accomplished by moving tape head 413 toward the central position and causing it to activate external limit switches, not shown, provided for sensing R-axis central head position. These limit switches generate voltage inputs to CNC computer during initial centering of tape head 413 about the R-axis for establishing a home condition. The CNC computer then generates voltage inputs through lead 917, and successively through voltage divider 914, through lead 915 to analog gate 916. Gate 916 is thereby turned ON upon receiving these enabling signals generated as the sensors (not shown) are tripped just prior to tape head 413 reaching a central position. When enabled, a circuit from lead 802 through potentiometer 917, lead 918, gate 916 to ground is completed. This, in conjunction with resistor 919 forms a voltage divider which attenuates the voltage signal applied through lead 812 to the Z-axis servosystem preventing override of the center axis position during R-axis movement approaching the central position. The CNC computer, by its internal program, then deactiviates the active relay section (relays 841, 842) and subsequentially removes controlled voltage to R-axis servomotor 72. Centering tape head 413 about the R-axis thereby provides its standardization for the initial starting operation. It can now be seen that the apparatus provides a new and improved means for tape application which alleviates many of the difficulties experienced in previous tape laying machines. For example, the cutting assembly 474 permits efficient cutting of fibrous tape 19 without the necessity of separating fibrous tape 19 from backing tape 112 prior to application to mold surface 412, and subsequent readhering of fibrous tape 19 to backing strip 112. The resin within fibrous tape 19 remains in the desired state of plasticity and tackiness, since it is not exposed to heat prior to its adherence to mold surface 412. Also, cutting along an angle skewed from the longitudinal axis of the tape can be accomplished without the necessary stopping X/Y axis movement of tape head 413.

Because of the use of dual X-axis tracks 14, 15 adapted to be mounted directly on a floor surface, and a conveniently transportable mold structure 412, apparatus 410 does not require the massive, integral, base structure employed in certain prior systems for supporting the work surface and gantry. Because of this mounting system, mold structure 412 may be conveniently positioned under gantry 11 between the X-axis ways, and may be mounted on permanently mounted, or detachable wheels, not shown, connectable to the lower portions of the supporting legs of the mold surface table, for permitting convenient transporting of the mold table and workpiece from tape laying machine 410 to an autoclave area, not shown, for curing of the workpiece while the composite structure workpiece formed from the remains on mold structure 412. This capability eliminates the requirement for transferring the workpiece from workstation to workstation during layup and processing, and makes more convenient the positioning of the work table under gantry 11. Mold 412 and supporting legs thus further comprise means for supporting the workpiece within an autoclave oven for curing.

The numerical control system, in combination with the particular electromechanical and pneumatic systems employed in apparatus 410 for actuation, position sensing, and calibration, provides the several advantages discussed above, and employs a commercially available numerical control computer system. Convenient programming is utilized in standard ASCII code format for various part configurations, while the complex position modifications required for Z and R-axis adjustment, to follow three dimensional mold contours, are accommodated by the pre-wired, adaptive control unit without the additional and substantially more expensive programming that would have been required. Additionally, the major axis, X, Y, and W, control provides efficient cutting of tape 110 along varying axes without the necessity of stopping X-Y movement of the tape laying head. Because of its control, position feedback, and cutting systems, the apparatus is operable to predetermine appropriate tape strip length, cutting angle, and point of initial application on mold 412 for lay-up of a workpiece of a desired configuration, without subsequent trimming, or with only a minor degree of post lay-up trimming. In addition to providing the above operational advantages, apparatus 410 is of

practicable manufacture and construction, employing commercially available components.

While only one embodiment of the apparatus, together with modifications thereof, has been described in detail herein and shown in the accompanying drawing, it will be evident that various further modifications are possible in the arrangement and construction of its components without departing from the scope of the invention.

Claims

1. An apparatus for manufacturing a composite structure of the type adapted for applying composite tape in a desired pattern to a receiving surface, comprising:

structure defining a mold surface;

first means, for containing and dispensing the tape;

second means, for translating the first means across the mold surface along selected paths;

third means having operator programmable means for defining a preselected pattern of tape lengths on the mold surface by cutting the tape into lengths corresponding to respective spacial dimensions of a desired configuration while said first means is being translated across said mold surface.

2. The apparatus of claim 1, the third means comprising a tape cutting means and control means for actuating the tape cutting means.

3. The apparatus of claim 2, the control means further comprising means, responsive to movement of the first means across the mold surface, for actuating the tape cutting means when the first means reaches a predetermined position relative to the mold surface.

4. Apparatus for manufacturing a composite structure from several layers of a composite tape material comprising:

(a) a mold surface corresponding to said structure;

(b) a first means for containing and dispensing said tape and including a means for contacting said mold surface;

(c) a second means for translating said first means across said mold surface;

(d) a third means having operator programmable means for causing said second means to translate across said mold surface along pre-selected paths; and

(e) a fourth means for causing said first means to dispense said tape onto said mold surface and including a shoe member for maintaining a substantially constant pressure on said tape.

5. An apparatus for manufacturing a structure from layered composite tape material comprising:

(a) a mold including a working surface corresponding to said structure;

(b) a first means for containing and dispensing said tape;

(c) a second means for translating said first means across said work surface said first means being operable to apply said tape onto said work surface while said first means is being translated across said work surface; and

(d) said first means including orienting means, means for contacting said work surface and sensing the contour thereof as said second means translates said first means across said work surface, and a signaling means for employing said contour sensing means to signal said orienting means for orienting said first means such that said first means is oriented substantially normal to said work surface.

6. The apparatus of claim 5 wherein said contacting means includes a shoe member that has a contact point for contacting said work surface and a guide chute for guiding said tape whereby said contact point tracks along the longitudinal center line of said tape.

7. The apparatus of claim 5 wherein said second means includes a gantry movably mounted on two mutually parallel tracks for movement in a first direction and means for moving said gantry along said tracks in said first direction, and said second means includes a tape applicator head movably mounted on said gantry for movement in a second direction and means for moving said tape applicator head along said gantry in said second direction and across the work surface of said mold structure.

8. The apparatus of claim 6 wherein said mold further includes a means for positioning said work surface relative to said first means within the operating range of said second means.

9. The apparatus of claim 5, 6, 7 or 8 wherein said orienting means includes a first positioning means for moving said first means in a generally radial direction relative to the contact point between said first means and said work surface and a second positioning means for moving said first means in a generally radial direction relative to the contact point between said first means and said work surface.

10. The apparatus of claim 5, 6, 7 or 8 wherein said contour sensing means includes a first sensing means for sensing the vertical position of said first means relative to the contact point between said first means and said work surface and a second sensing means for sensing the radial position of said first means relative to the contact point between said first means and said work surface.

11. An apparatus for manufacturing a structure from layered composite tape material comprising:

(a) a mold including a work surface corresponding to said structure;

(b) a first means for containing and dispensing said tape and including a means for contacting said mold surface;

(c) a second means for translating said first means across said work surface; and

(d) said first means including shoe member for applying pressure against said tape while said second means translates said first means across said work surface and means for maintaining said pressure substantially constant.

12. The apparatus of claim 11 wherein said contacting means includes a shoe member that has a contact point for contacting said work

surface and a guide chute for guiding said tape whereby said contact point tracks along the longitudinal center line of said tape.

13. The apparatus of claim 11 or 12 wherein said second means includes a gantry movably mounted on two mutually parallel tracks for movement in a first direction and means for moving said gantry along said tracks in said first direction and said first means includes a tape applicator head movably mounted on said gantry for movement in a second direction and means for moving said tape head along said gantry in said second direction and across said work surface of said mold structure.

14. The apparatus of claim 13 wherein said pressure applying means further comprises means for sensing the pressure against said composite tape as said tape is being applied to said work surface and adjusting means for adjusting said first means whereby a substantially constant pressure is directed against said tape while said tape is being applied to said work surface.

15. The apparatus of claim 13 wherein said mold further comprises a means for positioning said work surface relative to said first means and within the operation range of said second means.

16. An apparatus for manufacturing a structure from layered composite tape material comprising:

(a) a mold including a work surface corresponding to said structure;

(b) a first means for containing and dispensing said tape and including a means for contacting said work surface;

(c) a second means for translating said first means across said work surface;

(d) a cutting means for cutting said tape;

(e) operator programmable means for defining a preselected pattern of tape lengths corresponding to said work surface and for automatically activating said second means for automatically activating said cutting means to cut said tape into said lengths corresponding to said pattern while said first means is being translated across said work surface by said second means.

17. The apparatus of claim 16 wherein said second means includes a gantry movably mounted on two mutually parallel tracks for movement in a first direction and a first drive means for moving said gantry in said first direction, and said first means includes a tape applicator head movably mounted on said gantry for movement in a second direction and a second drive means for moving said tape applicator head along said gantry in said second direction and across the work surface of said mold structure.

18. The apparatus of claim 16 and 17 wherein said mold further comprise a means for positioning said work surface relative to said first means and within the operating range of said second means.

19. The apparatus of claim 16 or 17 wherein said cutting means further includes an orienting means to position said cutting means to cut said tape at a pre-selected angle.

20. An apparatus for applying a composite tape to a mold comprising:

a tape dispenser head; first means, for translating the dispenser head over the mold in a desired pattern; the first means having a gantry extending over the mold and gantry supporting means adapted to be mounted upon a supporting floor; second means movably supporting the mold upon the floor beneath the gantry.

21. The apparatus of claim 20, the mold surface comprising a contoured surface, the control means further comprising fourth means enabling the first means to follow the contour of the mold surface as the first means is translated across the mold surface.

22. The apparatus of claim 21, the control means including a numerically controlled digital computer and program means for directing the formation of the desired configuration, further comprising means for actuating the fourth means independently of the program means upon the first means being translated across the mold surface.

23. Apparatus for applying a composite tape to a mold in a desired pattern, comprising:

first and second tracks adapted to be mounted upon a floor surface in mutually parallel alignment, extending along a first axis, whereby a portion of the floor surface may extend between the tracks;

a mold structure adapted to be positioned on the floor surface between the first and second tracks; tape dispenser means;

gantry means for supporting the dispenser means over the floor surface extending between the first and second tracks, the gantry means having drive means for engaging the first and second tracks and for translating the gantry means along the tracks;

means for translating the tape dispenser means along the gantry means.

24. The apparatus of claim 23, the mold structure having support means, having vertical extensions, for engaging the floor surface and for positioning the mold between the first and second tracks at a predetermined height over the floor surface.

25. The apparatus of claim 23, the mold structure having supporting means for positioning the mold between the first and second tracks at a predetermined height over the floor surface and for movably engaging the floor surface for permitting movement of the mold relative to the floor surface.

26. The apparatus of claim 25, the support means for positioning the mold between the first and second tracks at a predetermined height above the floor surface further comprising means for supporting the mold within an autoclave oven.

27. An apparatus for applying a composite tape to a mold, comprising:

a tape dispenser head for dispensing the composite tape; a mold having surface adapted for receiving the tape; gantry means for

translating the dispenser head over the mold in a desired pattern;

control means for defining a preselected pattern of tape lengths on the mold surface by activating the dispenser head to cut the tape into lengths corresponding to respective lateral dimensions of a selected pattern.

28. The apparatus of claim 27, the tape dispenser head having a supply reel, comprising means adapted to receive a composite tape structure having a fibrous strip impregnated with an uncured resin, and a backing strip adjacent the fibrous strip; further comprising means having a blade and means for translating the blade across and through the fibrous tape layer and adjacent the backing strip, the means translating the blade comprising means preventing serration of the backing strip.

29. The apparatus of claim 28, the cutting means comprising means for cutting fibrous composite tape extending between the supply reel and the applicator means.

30. The apparatus of claim 29, the cutting means comprising blade means and means for translating the blade means across the composite tape.

31. The apparatus of claim 29, including means mounting the cutting blade means and exposing a selectable cutting blade height projecting toward the tape structure by a distance substantially equal to the thickness of the fibrous tape.

32. Apparatus for applying a composite tape, adhered to a backing strip, to a mold surface, comprising:

an applicator means for urging the composite tape against the mold and for adhering the composite tape to the mold surface;

means for separating the backing strip from the fibrous strip adhered to the mold surface, said means including take-up reel means for collecting the backing strip and for imparting tension to the backing strip for stripping it from the composite tape;

cutting means for cutting the fibrous tape.

33. The apparatus of claim 32, the means for separating the fibrous tape from the backing tape further comprising tensioning means for collecting the backing strip which is separated from the fibrous tape while sustaining tension on the backing strip extending between the supply reel and the take-up reel.

34. The apparatus of claim 33, further comprising means for translating the applicator means and the tensioning means between a first relative orientation, in which the applicator means is positioned adjacent the mold surface and comprises means urging the tape structure against the mold surface and in which the tensioning means is spaced from the mold surface and comprises means guiding the backup tape along a path spaced from the mold surface and spaced from the fibrous tape applied to the mold surface, and a second relative orientation in which the applicator means is spaced from the mold surface and the tensioning means is positioned adjacent the mold surface and comprises means urging a portion of the backing strip which has been separated from the fibrous tape into contact with the fibrous tape which has been adhered to the mold surface, the applicator means and the tensioning means comprising, when in their second relative orientation, means guiding the fibrous tape from the applicator means toward the tensioning means and into contact with the mold surface and thereby defining a tensioned length of the fibrous tape extending between the applicator means and the tensioning means.

35. The apparatus of claim 34, cutter means comprising means for cutting the tensioned length of fibrous tape extending between the applicator means and the tensioning means when the applicator means and tensioning means are in their second relative orientation.

36. The apparatus of claim 32, the cutting means comprising means for cutting composite tape which is adjacent a backing strip.

37. A tape applicator head for applying a tape to a mold that includes a work surface for receiving said tape comprising:

(a) support means;

(b) a tape containing and dispensing means operatively attached to said support means;

(c) drive means for moving said tape containing and dispensing means across said work surface;

(d) means for bringing said tape into contact with said work surface; and

(e) means including a shoe member for applying a pressure to said tape while said tape is in contact with said work surface and for maintaining said pressure on said tape while said tape applicator head moves across said mold surface.

38. The tape head of claim 37 wherein said means for bringing said tape into contact with said work surface further includes a guide chute which guides said tape to said shoe member whereby said shoe member applies pressure along the longitudinal axis of said tape.

39. The tape applicator head of claim 37 or 38 further comprising means for sensing the pressure against said tape and means for signaling said pressure applying means from said pressure sensing means whereby to maintain a substantially constant pressure against said tape.

40. The tape applicator head of claim 39 further comprising a means for cutting said composite tape.

41. The tape applicator head of 40 wherein said cutting means further includes an orienting means to position said cutting means to cut said tape at a pre-selected angle.

42. The tape applicator of claim 41 further comprising an operator programmable means for controlling said drive means said means for bringing said tape into contact with said work surface and said tape cutting means.

43. A tape applicator head for applying a tape to a mold that includes a work surface for receiving said tape comprising:

(a) support means;

(b) a tape containing and dispensing means operatively attached to said support means;

(c) drive means for moving said tape containing and dispensing means across said work surface;

(d) means for bringing said tape into contact with said work surface and for maintaining such contact; and

(e) means for cutting said tape while said tape applicator head continues to move across said work surface.

44. The tape applicator head of claim 43 wherein said means for bringing said tape into contact with said work surface includes a shoe member and a guide chute for guiding said tape to said shoe member whereby said shoe member tracks along the longitudinal center line of said tape.

45. The tape applicator head of claim 43 wherein said cutting means further includes an orienting means to position said cutting means to cut said tape at a pre-selected angle.

46. The tape applicator head of claim 43, 44, or 45 further comprising an operator programmable means for independently controlling each of said drive means, said means for bringing said tape into contact with said work surface and said tape cutting means.

47. A tape applicator head for applying a tape to a mold that includes a work surface for receiving said tape comprising:

(a) support means;

(b) a tape containing and dispensing means operatively attached to said support means;

(c) drive means for moving said tape containing and dispensing means across said mold surface;

(d) means for bringing said tape into contact with said work surface and for maintaining such contact;

(e) said means for contacting said work surface including a means for sensing the contour of said work surface at the contact point between said tape head and said work surface while said drive means translates said tape head across said work surface;

(f) orienting means; and

(g) signaling means to signal said orienting means for orienting said tape applicator head such that said tape head is oriented substantially normal to said work surface.

48. The tape applicator head of claim 47 wherein said contacting means includes a guide chute for guiding said tape to said contact point whereby said contact point tracks along the longitudinal axis of said tape.

49. The tape applicator head of claim 47 wherein said orienting means includes a first positioning means for moving said tape applicator head in a generally vertical direction relative to the contact point between said tape applicator head and said work surface and a second positioning means for moving said tape applicator head in a generally radial direction relative to the contact point between said tape applicator head and said work surface.

50. The tape applicator head of claim 47, 48 or 49 wherein said sensing means includes a first sensing means for sensing the vertical position of the tape applicator head relative to the contact point between the tape applicator head and the work surface and a second sensing means for sensing the radial position of the tape applicator head relative to the contact point between the tape head and the work surface.

51. A tape applicator head for applying a tape material to a mold that includes a work surface for receiving said tape comprising:

(a) support means;

(b) a tape containing and dispensing means operatively attached to said support means;

(c) drive means for moving said tape containing and dispensing means across said work surface;

(d) means for bringing said tape into contact with said work surface and including a shoe member for maintaining such contact;

(e) a means for cutting said tape; and

(f) operator programmable means for defining a preselected pattern of tape lengths, said pattern corresponding to said work surface, and for automatically activating said drive means and said means for bringing said tape into contact with said work surface and also for automatically activating said cutting means to cut said tape into lengths corresponding to said pattern while said tape head is being translated across said work surface.

52. The apparatus of claim 51 wherein said cutting means further includes an orienting means to position said cutting means to a pre-selected angle.

53. An automatic tracking system for providing control information to a work structure that is movable with respect to a work surface and in which said work structure is initially and primarily controlled by a program input in its movement through a longitudinal X-axis, a transverse Y-axis and a rotational C-axis relative to said work surface and is controlled by said program input in its movement through a vertical Z axis relative to said work surface to bring a contact point of said work structure into contact with said work surface at the beginning of said program input and to disengage said contact point from contact with said work surface at the end of said program input, comprising a means for orienting said contact point, an adaptive control means for sensing the contour of said work surface at said contact point as said work structure moves across said work surface and a signaling means to signal said orienting means for orienting said contact point such that said contact area is oriented substantially normal to said work surface.

54. The automatic tracking system of claim 53 wherein said orienting means further comprises a first positioning means for moving said work structure in a generally vertical direction relative to the contact point between said work structure and said work surface a second positioning means for moving said work structure in a generally radial direction relative to the contact

point between said work structure and said work surface.

55. The automatic tracking system of claim 53 or 54 wherein said adaptive control contour sensing means further comprises a first sensing means for sensing the vertical change of said work surface relative to the contact point between said work structure and said work surface and for signaling said orienting means to orient said work structure to follow said vertical change of said work surface and a second sensing means for sensing the radial change of said work surface relative to the contact point between said work structure and said work surface and for signaling said orienting means to orient said work structure to follow said radial change of said work surface.

56. The automatic tracking system of claim 55 further comprising a contacting means including a shoe member for causing said contact area of said work structure to contact said work surface at a substantially constant pressure.

57. An apparatus for manufacturing a composite structure of the type adapted for applying composite tape in a desired pattern to a receiving surface, comprising:

structure defining a mold surface;

first means for containing and dispensing the tape;

second means, for translating the first means across the mold surface along selected paths;

third means, having operator programmable means, for defining a preselected pattern of tape lengths on the mold surface by cutting the tape into lengths corresponding to respective spacial dimensions of a desired configuration while said first means is being translated across said mold surface;

fourth means, responsive to elevationed variances in the mold surface, for causing the first means to track the contour of the mold surface during translation of the first means across the mold surface.

58. An apparatus for manufacturing three dimensionally contoured composite structures comprised of layers of adherently bonded flexible tape formed in a desired pattern on a removeable contoured receiving surface, said apparatus comprising:

(a) a support structure;

(b) first means moveably mounted on said support structure including tape dispenser means for controllably dispensing said tape and cutter means for controllably cutting said tape;

(c) a bed member for supporting a mold having a contoured receiving surface;

(d) second means for selectively at least horizontally moving said first means with respect to said contoured receiving surface along selected paths, said first means being controlleable to dispense said tape over said receiving surface as said first means is selectively moved with respect thereto;

(e) control means including:

(i) user programable third means coupled to said second means and responsive to digital coordinate data for controlling said second means to selectively move said first means over the receiving surface to dispense said tape on said receiving surface and for controlling said cutter means to selectively cut said tape into lengths corresponding to the outer dimensions of said receiving surface as defined by said digital coordinate data while said first means is being moved across said receiving surface; and,

(ii) automatic fourth means operating independently of said third means including sensor means for detecting the contour of said surface and means coupled to said second means for vertically positioning said first means with respect to said contoured receiving surface.

59. The apparatus according to claim 58 where said programmable third means includes means for grossly controlling the vertical position of said first means and said automatic fourth means includes means for finely controlling the vertical position of said first means.

60. The apparatus according to claim 59 wherein said first means is radially moveable about an axis and wherein said automatic fourth means includes means for controlling the position of said first means about said axis to follow the contour of said receiving surface.

61. Method for an operator to manufacture a composite structure from layered composite tape material comprising employing apparatus of the type having a means for containing and dispensing said tape operably mounted to a support means, and a means for moving said tape containing and dispensing means:

(a) defining a mold corresponding to said composite structure and having a work surface for receiving said tape;

(b) defining an appropriate pattern for lengths of said composite tape corresponding to said work surface;

(c) inserting said composite tape into said means for containing and dispensing said tape;

(d) bringing said tape contained in said tape containing and dispensing means into contact with said work surface;

(e) energizing said means for moving said tape containing and dispensing means; and

(f) guiding said moving means across said work surface according to said pattern of lengths of said tape while simultaneously energizing said tape dispensing means to thereby apply said tape to said work surface in the required lengths.

62. An apparatus for manufacturing a structure from layered composite tape material comprising:

(a) a gantry movably mounted on two mutually parallel tracks for movement in a first direction, said gantry having drive means for engaging said tracks and for moving said gantry along said tracks;

(b) a tape applicator head movably mounted on

said gantry for movement in a second direction perpendicular to said first direction;

(c) a drive means for moving said tape applicator head along said gantry;

(d) a mold surface corresponding to one of the outer surfaces of said structure and which is positioned between said tracks and within the range of the movement of said gantry and said tape head;

(e) an operator programmable means associated with said gantry and with said tape head for defining pre-selected paths along which said gantry and said tape head will move;

(f) said tape head comprising a tape containing and dispensing means including a supply reel and a take-up reel attached to a mounting plate, said mounting plate being attached to a vertical drive means for moving said mounting plate in a generally vertical direction, said vertical drive means being mounted to a radial drive means for movement in a radial direction relative to said mounting plate; a means for bringing said tape into contact with said mold surface including a shoe member for maintaining a constant pressure on said tape and a guide chute for guiding said tape to said shoe member whereby said shoe member tracks along the longitudinal axis of said tape;

(g) a tape cutting means including a stylus housing having a stylus that is pre-positioned a distance beyond the end of said housing substantially equal to the thickness of said tape and in a direction facing the path of said tape and in which said stylus is rotatably mounted in said stylus housing and can be programmed by said operator programmable means to cut said tape at a pre-selected angle while said tape head continues to translate across said work surface, and an anvil member that is spring loaded in a direction away from said stylus and is moved into contact with said stylus by an operator programmable actuator means,

(h) a mold surface tracking means including a first sensor for detecting the vertical change in the contour of said mold surface and a means for signaling said vertical drive means for vertically positioning said tape head to follow said vertical change and a second sensor for detecting the radial change in the contour of said mold surface and a means for signaling said radial drive means for radially positioning said tape head to follow said radial change, said sensors thereby acting to orient said tape head substantially normal to said mold surface and to maintain a substantially constant pressure on said tape as said tape is being applied to said mold surface.

63. Method for automatically tracking a work surface with a device of the type having a detection head movably mounted on said device, a first drive means for transporting said detection head vertically into and out of contact with said work surface, a second drive means for transporting said detection head across said work surface, and a third drive means for radially positioning said detection head, said detection head including a first sensor for detecting the vertical change in the contour of said work surface and for signaling said first drive means to adjust said detection head to follow said vertical change, and a second sensor for detecting the radial change in the contour of said work surface and for signaling said third drive means to adjust said detection head to follow said radial change, comprising the steps of:

(a) energizing said first drive means until said detection head contacts said work surface;

(b) energizing said third drive means until said detection head is oriented substantially normal to said work surface;

(c) adjusting said first sensor to correspond to a plane normal to the contact point between said detection head and said work surface and to signal said first drive means to adjust said detection head vertically an amount corresponding to the vertical change in said work surface;

(d) adjusting said second sensor to correspond to a plane normal to the contact point between said detection head and said work surface and to signal said third drive means to adjust said detection head radially an amount corresponding to the radial change in said work surface; and

(e) energizing said second drive means to transport said detection head across said work surface whereby said first and said second sensors will continuously signal said first drive means and said third drive means, respectively, to orient said detection head to remain substantially normal to said work surface.

64. Apparatus for manufacturing a composite structure substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

65. Apparatus for applying a composite tape to a mold in a desired pattern substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

66. A tape applicator head for applying a tape to a mold substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

67. An automatic tracking system for providing control information to a work structure substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

68. A method for an operator to manufacture a composite structure substantially as hereinbefore described.

69. A method for automatically tracking a work surface substantially as hereinbefore described.

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